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ORIGINAL ARTICLES.

The Formation of Inselberge.

By A. D. N. Bain, M.Sc., F.G.S.

(PLATES I AND II.)

1. Inselberge, which form striking features in the landscape of most of tropical Africa, have attracted the attention of many writers, and various theories have been advanced to explain their formation. Passarge (1)[1] considered that desert conditions are the most favourable for their maintenance, as wind scour was believed to be a potent factor in the deepening of the hollows between them. Bornhardt (2) and Falconer (3) suggest that they may result from repeated cycles of pluvial erosion, due to normal crustal oscillations, and with this view Theile and Wilson agree (4). From a study of the inselberge in Nigeria, the writer will endeavour to show that the climate of the Sudan, with its alternate wet and dry seasons, is favourable to the production of inselberg landscape.

2. In certain parts of Nigeria inselberge are exceptionally well developed, and can be studied in all stages of development and disintegration. Though not confined to the Sudan, they are most abundant and most perfectly formed in that part of the country, and good examples are to be seen in the drier parts of the coastal belt, as at Eruwa, 60 miles inland (Text-fig. 1), where orchard bush has succeeded tropical forest, and east of Ikirun, 120 miles inland, on the edge of the tropical forest belt. Excellent examples occur in the Lemmi district, in the western Sudan, 500 miles from the coast and 50 miles north of Jos in the tin-fields area, which lies in the centre of a wide stretch of inselberg country.

3. Only two types of inselberge seem to occur in Nigeria, viz. (*a*) dome-shaped, rising steeply from the plains and generally unscalable, (*b*) less perfectly shaped and sometimes with a precipitous side (Pl. II, Fig. 3), occasionally sloping gently to the plain in one direction, and usually scalable. These two types are composed of different rocks, the first of coarse-textured porphyritic granite-gneiss, and the second may be of various kinds of gneiss, generally of a fine compact nature, commonly an acid granitoid rock, but sometimes a banded granitoid gneiss, which may occasionally embody bands of hornblende schist, as at Ringi, north of Lemmi. At Eruwa and Ikirun inselberge of the first type

[1] Numbers in parentheses refer to bibliography at end of paper.

only are found (5). Quartzo-felspathic veins, though very abundant in the banded gneisses (6), are not known to be responsible for any inselberg, and in most instances are conspicuously absent. Pegmatite, however, where massive and penetrating schists and soft gneisses forms low hills, but where intrusive into granitic gneiss, as at Ikirun, it weathers more rapidly than the gneiss, and in some cases dykes of pegmatite are marked by lines of drainage. In this respect Nigeria may be contrasted with Mozambique (7). In the Plateau granite of the tin-fields area (8) detached inselberge are not yet formed, but long, bare ridges, having all the characteristics of inselberge, are universally developed. These are separated by deep, straight, and almost vertical-walled valleys, the positions of which are determined by major joints.

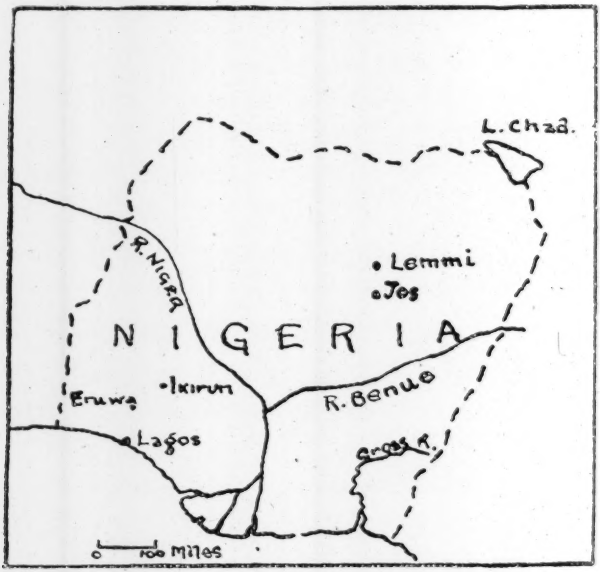
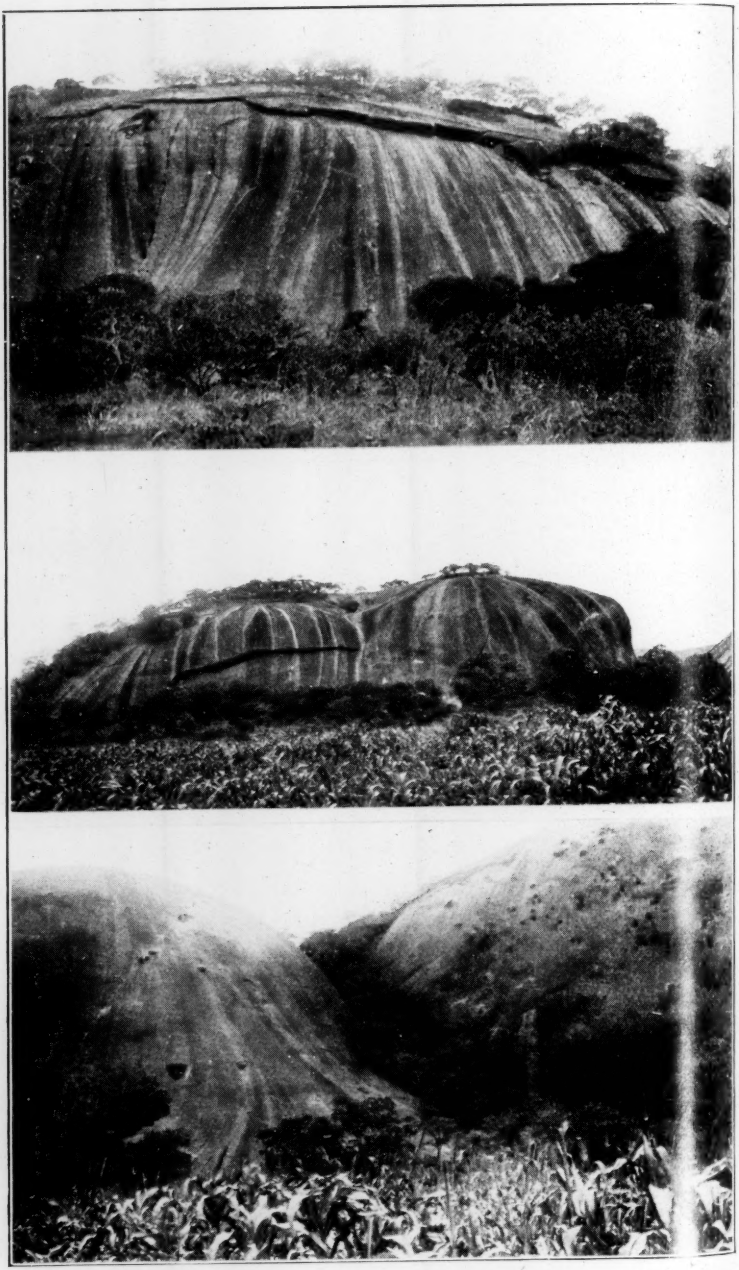


Fig. 1.—Sketch-map of Nigeria, showing localities mentioned in text.

4. The main factors which seem to determine the formation of these hills are :—

(*a*) Climate.
(*b*) Jointing.
(*c*) Nature of the rock.

In the crystalline rocks of Nigeria, except locally, good jointing is developed only on a very large scale, and it can be definitely seen that weathering progresses very rapidly along these fractures. Assuming that the surface of the country when it was first attacked by the ordinary agents of weathering, was irregular, moisture and



Inselberge near Lemmi, Nigeria.

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heat in a Sudan climate, with alternate wet and dry seasons, would quickly deepen any hollows already formed. Under such conditions chemical action is extremely rapid, especially along cracks where water collects and vegetation takes root, preventing rapid evaporation or drainage. The result is that hollows due to slight surface irregularities and joint cracks soon become deepened by this means, while the bare rocks between weather by exfoliation only. During the wet season the small streams which are choked with sand, the residue from the chemical decomposition of the rocks, are cleared, and thus a fresh surface of rock is exposed to the chemical action of the moisture and the organic acids from the vegetation growing along the valleys. As vegetation protects the water left in the valley at the end of the wet season when the streams become a chain of pools, chemical action is prolonged and deep gorge-like valleys with bare residual ridges result, which break up by a similar process of weathering along cross joints into steep-sided isolated hills. Thus it is that the inselberge are frequently found to be composed of the same rock as the low ground between them, the weathering agents having eaten back into the unbroken rock mass, leaving only the residual inselberge. The nature of the rock is not of such importance as the other two factors, although uniformity of texture and absence of strong foliation go to make more perfect inselberge.

5. There are some interesting facts about these hills which it might be useful to record. The apparently smooth surfaces are often very rough, especially where they are not often scoured by rain wash. In such places the felspar and quartz crystals stand out in bold relief, and though the surface is even in a general sense, at close quarters it is jagged and file-like.

6. Exfoliation takes place by large slabs cracking from the outer shell, which has become separated from the main rock mass by alternate expansion and contraction under the diurnal temperature changes, which may be as much as 60° F. in the dry season. The slabs break away from the lower flanks, leaving the higher portion of the layer presenting a concave surface to the plain (Pl. II, Fig. 2). This surface retreats till a mere cap remains on the top of the hill, by which time another layer has begun to be removed, so that two shells are frequently being removed about the same time. The thickness of these layers varies between 1 and 5 feet, but exceptionally a layer may reach as much as 15 feet, as in the case of the inselberg ridge at Nafuta, south of Lemmi. This is in Plateau granite. A common thickness is about 2 feet. Trees growing in the surface cracks send roots underneath the exfoliating layer and help to separate it from the hill, so that slabs are forced up and cracked into blocks by this means.

7. Running water draining from the vegetation growing amongst the blocks left from the breaking up of an exfoliated layer on the top of an inselberg (Pl. I, Fig. 1) has practically no power to corrade

mechanically, as it is spread out in a mere film and is free from sediment. Its dissolving power, however, is enhanced by the organic acids from the vegetation. Similarly in water-filled hollows rank grasses, algæ, and other organic bodies thrive, and the organic acid from these rots the granitic rock at a greater rate than the edge can be worn by the overflowing water in the wet season, and the hollows are consequently rapidly deepened. Some of these cylindrical holes penetrate the exfoliated layer, and the water in the wet season disappears into them to reappear lower down the flank of the hill, as a film of water sliding down the bare rock. These thin streams remove the superficial dark-brown layer, and when they cease to flow leave clean, white streaks to mark their former paths (Pl. I, Fig. 2).

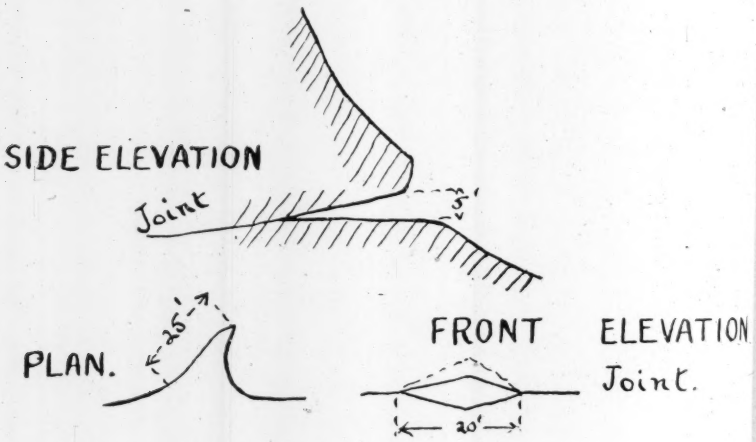

Fig. 2.—Cave formed by solution along a joint.

8. Horizontal as well as vertical joints play a part in the production of solution cavities, and one of these (9) was found to extend a distance of 25 feet in the hillside, to be 20 feet wide, and about 15 feet high at the mouth (see Text-fig. 2). A slight hollow at the outcrop of this joint plane must have allowed water to collect and decompose the rock so that the hollow became gradually bigger and is now a cave.

It would, therefore, seem that weathering, especially solution weathering, along major joint cracks in a Sudan climate results in the production of inselberg landscape.

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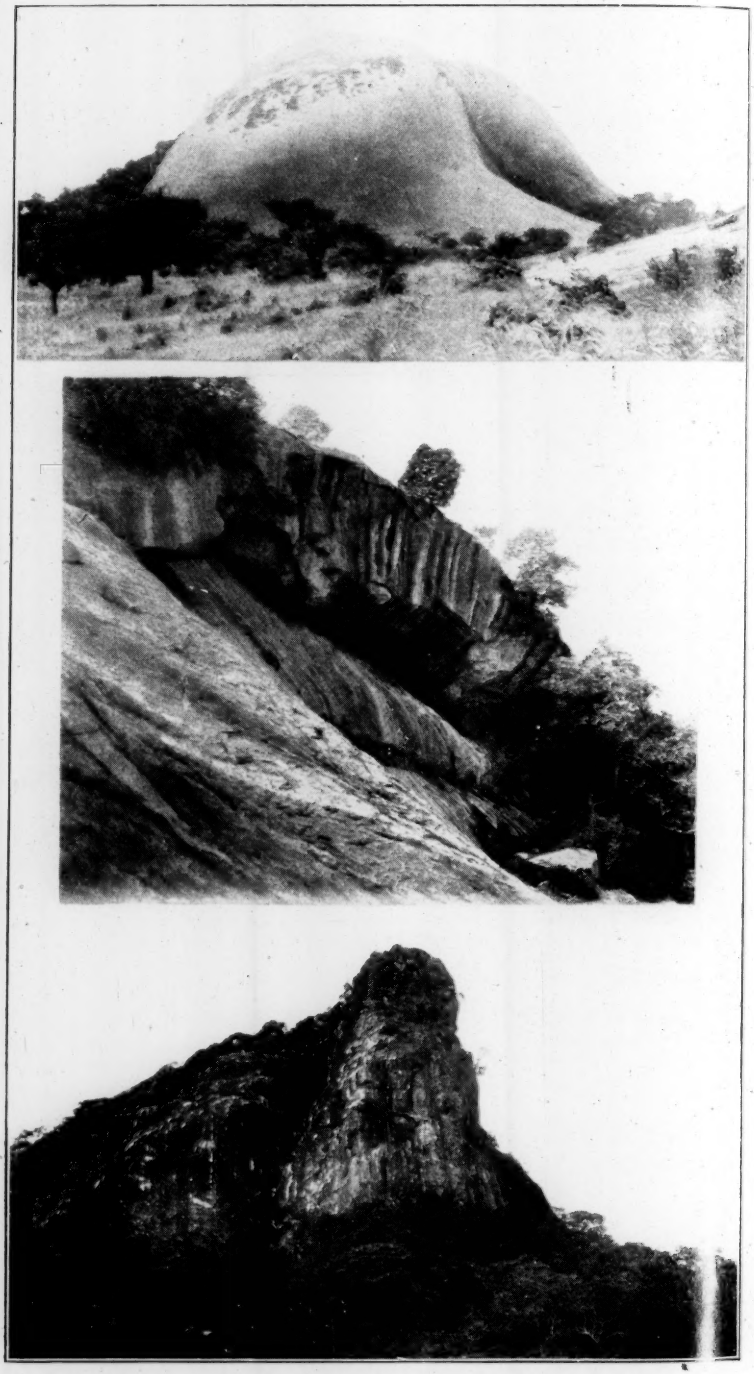

INSELBERGE NEAR LEMMI, NIGERIA.

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(2) W. Bornhardt, *Die Oberflachengestaltung und Geologie Deutsch-Ost Afrikas*, vol. vii, Berlin, 1910, pp. 34–9.
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(4) E. O. Theile and R. C. Wilson, *Geogr. Journ.*, vol. xlv, 1915, pp. 27, 30.
(5) *Geol. Surv. of Nigeria*, Bulletin No. 2, pp. 44–6.
(6) Ibid., p. 32 et seq.
(7) A. Holmes, *Q.J.G.S.*, vol. lxxiv, 1918, pp. 89–93.
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EXPLANATION OF PLATES.

Plate I.

Fig. 1.—The first stage in the division of an inselberg along a joint crack. On top of the hill are the relics of an exfoliated layer with trees growing between the cracks. From Shan, 10 miles north of Lemmi.
„ 2.—A later stage in the division along a joint. From Shan.
„ 3.—A ridge divided into two inselberge by solution along a joint. From Shan.

Plate II.

Fig. 1.—The twin inselberge separated by the joint crack shown in Plate I, Fig. 3. The height of these is about 300 feet, and the rock is coarse-textured porphyritic granite gneiss. From Shan.
„ 2.—A thick exfoliating layer in acid granitoid gneiss. From Delimi Habe, 20 miles east of Lemmi.
„ 3.—The truncated end of a less perfectly formed inselberg composed of acid granitoid gneiss. From Mundu, 10 miles east of Lemmi.

Paragenesis of the Minerals of the Three Component System MgO-Al_2O_3-SiO_2 in Thermal Metamorphism.

By C. E. Tilley.

THE system magnesia-alumina-silica is one of great importance in petrology, and the paragenesis of its constituent minerals must be a subject of study in any enquiry into the thermal metamorphism of rocks which have these three components as important constituents. Such rocks include particularly those of argillaceous type, magnesian-carbonate sediments, and bauxitic rocks.

The minerals comprised within this system are the following twelve types, apart from their polymorphic modifications :—

MgO (Periclase).	$MgAl_2O_4$ (Spinel).
Al_2O_3 (Corundum).	$Mg_2Al_4Si_5O_{18}$ (Cordierite).
SiO_2 (Quartz).	$Mg_3Al_2Si_3O_{12}$ (Pyrope).
$MgSiO_3$ (Enstatite).	$Mg_5Al_{12}Si_2O_{27}$ (Sapphirine).
Mg_2SiO_4 (Forsterite).	$MgAl_2SiO_6$ (Prismatine).
Al_2SiO_5 (Andalusite).	$Al_{20}Si_7O_{41}$ (Dumortierite).

Of these types the first eight alone appear as phases in the dry melt investigations of the laboratory. Of the remaining four, it

may be remarked that the pure pyrope has not yet been recorded in rocks, the studies of Eskola indicating that magnesian garnets show molecular percentages not exceeding seventy-five, of the pyrope type. This mineral does not appear in thermally altered dolomites. The conditions of formation of prismatine (kornerupine) and sapphirine are unknown, but in the rare occurrences of these minerals there is some evidence to consider them as stress minerals. Dumortierite is a rare constituent of granite pegmatites, and often contains notable amounts of boron, and it is not clear whether this is not an essential constituent.

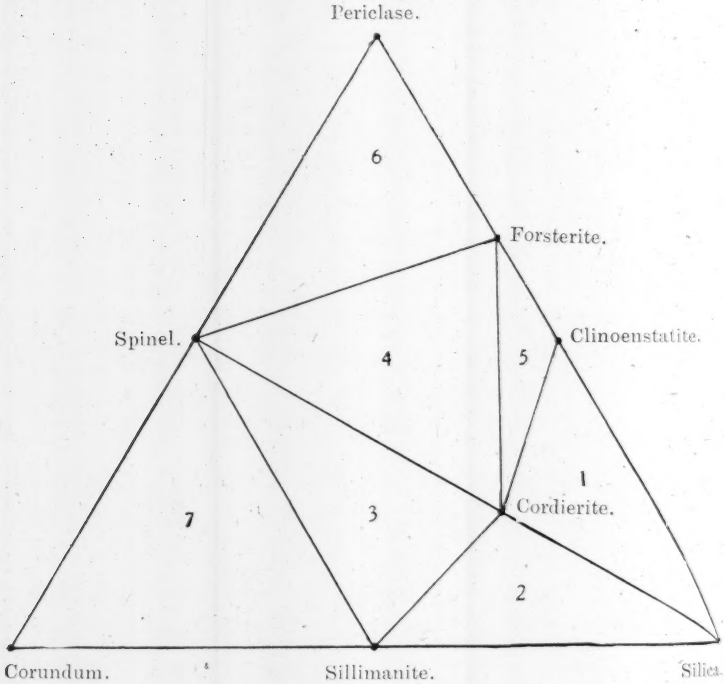


FIG. 1.—Equilibrium assemblages in the dry melt system MgO-Al_2O_3-SiO_2.

The investigation of the system MgO-Al_2O_3-SiO_2 in anhydrous melts we owe to Rankin and Merwin.[1] It is characterized by four binary and one ternary compound, these, together with the oxide phases, forming the eight phases enumerated above.

From the equilibrium diagram which these investigators have determined, we can construct a diagram showing the final products of crystallization for melts of composition within the system. These,

[1] The Ternary system MgO–Al_2O_3–SiO_2, G. A. Rankin and H. E. Merwin, *Amer. Journ. Sci.*, vol. xlv, 1918, p. 301.

of course, represent true equilibrium conditions, and are indicated in Fig. 1.

Melts of composition represented within the boundaries of the triangular areas 1, 2, 3, etc., are with equilibrium crystallization represented by the crystalline assemblages of the minerals whose compositions are indicated by the apices of the respective triangles.

The following three-phase assemblages are realized :—

1. Cordierite silica clinoenstatite.
2. Cordierite silica sillimanite.
3. Cordierite sillimanite spinel.
4. Cordierite spinel forsterite.
5. Cordierite clinoenstatite forsterite.
6. Periclase spinel forsterite.
7. Corundum spinel sillimanite.

It is now of interest to see in how far these equilibrium assemblages are represented amongst natural rocks, and more especially amongst rocks which have recrystallized under conditions of thermal metamorphism. It is first to be noted that all of the eight minerals appear as constituents of thermally metamorphosed sediments, with the exception that enstatite appears instead of clinoenstatite, and andalusite often in place of sillimanite.

In dealing with natural rocks it is clear that systems of more than three components are involved. The principal remaining components appearing in rocks are CaO, Na_2O, K_2O, FeO, Fe_2O_3, H_2O. These introduce new phases, such as plagioclase, orthoclase, biotite, magnetite, etc. The magnesia compounds of the three-component system are represented among rock-forming minerals by compounds in which FeO often largely replaces MgO, but it would appear that unless very large amounts of FeO are involved, no new phases would appear in the dry melt system, although, as Rankin and Merwin have pointed out, the temperature relations within the system would be considerably disturbed. That in natural systems FeO may be considered as replacing MgO, and not introducing a new component, seems reasonable, provided too large amounts of FeO are not involved.

With very high FeO content it is possible that cordierite may disappear, and it is of interest to note that available analyses of rock-forming cordierites show a limiting value of the FeO content.

In considering the three-phase assemblages of natural rocks of the magnesia-alumina-silica system, and comparing them with those revealed under equilibrium conditions in the dry melt system, the entry of other constituents cannot be ignored, for it is possible that besides introducing new phases the character of the assemblage may be changed.

V. M. Goldschmidt has shortly considered the system in connexion with his study of the Kristiania contact zones, but as the silica-poor

type of hornfels is not recorded for that area, only the silica rich compositions have been dealt with by him.

Considering Fig. 1, we find that a number of three-phase assemblages there given are realized in nature. These are :—

(1) Cordierite quartz enstatite.

Such rock assemblages with the additional minerals, biotite, plagioclase, and potash felspar, are recorded by Erdmannsdörffer, Goldschmidt, and others.

(2) Cordierite quartz andalusite.

This is the common type of hornfels of argillaceous composition.

(3) Cordierite Al_2SiO_5 spinel.

Hornfelses of this type are well known amongst metamorphosed sediments. Such have been described by Erdmannsdörffer, from the Harz, as inclusions in the Land's End granite (Flett), and in Aberdeenshire (Teall).

(6) Periclase spinel forsterite.

This assemblage is characteristic of thermally metamorphosed dolomites.

(7) Corundum spinel Al_2SiO_5.

This assemblage is, perhaps, realized among "Schmirgel und Spinel Gesteine", or Group XII of Grubenmann's classification of metamorphic rocks. It would appear to be present in the aureole of the Ben Cruachan granite, Scotland (Teall).

The remaining dry melt assemblages, namely, (4) and (5), do not appear to occur amongst natural rocks.

Before considering these, however, it may be noted that other assemblages, not realized in Fig. 1, are found amongst natural rocks. Such are, for example :—

(8) Corundum cordierite Al_2SiO_5.
(9) Corundum cordierite spinel.
and
(10) Spinel enstatite cordierite.
(11) Spinel enstatite forsterite.

We may consider assemblages (8) and (9) first. They are, indeed, alternative assemblages to numbers (3) and (7).

Amongst natural rocks, therefore, there appear to be the following related four assemblages :—

(3) Cordierite Al_2SiO_5 spinel.
(7) Corundum spinel Al_2SiO_5.
(8) Corundum cordierite Al_2SiO_5.
(9) Corundum cordierite spinel.

A preliminary study of the hornfelses surrounding the Caledonian diorite intrusion of Comrie, Perthshire, revealed a number of corundum-bearing types. So far recognized, these comprise only types (8) and (9). The associated minerals are felspars, plagioclase and orthoclase, biotite and magnetite.

These associated minerals are, in fact, those recognized amongst assemblages of (3) and (7), and this close similarity in bulk composition of the four assemblages, as known in natural rocks, strengthens the view that we are here dealing with a reversible system of the type $A + B \rightleftharpoons C + D$, in which the phases introduced by new components (as plagioclase, etc.) appear without disturbing the reversible relations.

The presence of spinel in assemblage (8) is inhibited by a reaction of the type

$$2\,MgAl_2O_4 + 5Al_2SiO_5 \rightleftharpoons Mg_2Al_4Si_5O_{18} + 5Al_2O_3$$

the four phases appearing together at the transformation point.

Of these four assemblages, the corundum hornfelses (8) and (9) appear to represent the low temperature associations.

The validity of these suggested relations, it must be admitted however, must await experimental work on systems which contain FeO as a constituent oxide.

The assemblages

(4) Cordierite spinel forsterite
(5) Cordierite $MgSiO_3$ forsterite

of the dry melt system are unknown amongst natural rocks. If it were possible to consider the combinations, cordierite-forsterite and spinel-enstatite, as reversible pairs, then we should expect that the cordierite-forsterite association would be the stable assemblage at higher temperatures.

The absence, however, of this association in nature, whether from metamorphosed sediments or from basic igneous rocks, is a clear warning that caution is necessary.

The reversible relations have not been proved, and the influence of other oxides which enter the system, and as such play a part in natural rocks, must be considered. This influence may be felt, not only in the introduction of new phases, but also in a modification of the character of the assemblage. It is easy to see that FeO added to this three-component system will (probably without adding new phases or destroying the present phases) change considerably the shapes of the stability fields, and it is possible that the boundary curve between cordierite and forsterite might be replaced by a similar one between spinel and the magnesium metasilicate.

Whatever be the case, it is clear that amongst natural rocks the cordierite forsterite association is not a stable association, and

assemblages (4) and (5) of the dry melt system are represented by

(10) Spinel enstatite cordierite
(11) Spinel enstatite forsterite.

The latter type is too highly magnesian to be found amongst metamorphosed sediments, and is realized amongst basic igneous rocks with anorthite in the four-component system.

The spinel enstatite assemblage is, however, realized amongst hornfelses, and as such is found in the thermal aureole of the diorite mass of Comrie, Perthshire. Here, enclosed in pleochroic hypersthene porphyroblasts, occur numerous grains of green spinel. The additional components, CaO, etc., are represented by abundant plagioclase, biotite, etc., as additional phases.

The three-phase assemblages of natural rocks, i.e. the assemblages which occur in association with phases introduced by the additional components, which go to form natural rock types, may be represented diagrammatically, as in Fig. 2.

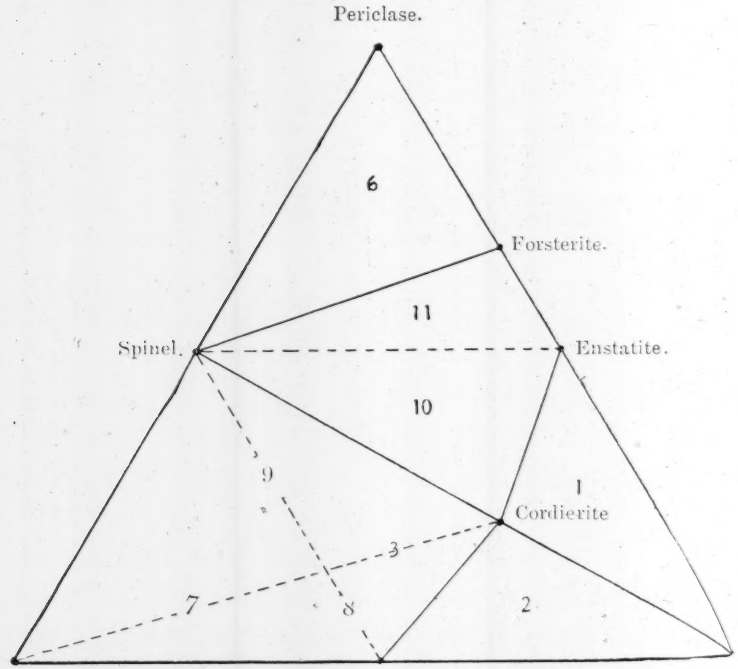


FIG. 2.—Assemblages in natural rocks.

These natural assemblages may be tabulated in summary in the following order :—

Hornfels or Assemblage Type.	*Mode of Occurrence, etc.*
1. Cordierite quartz enstatite . .	Hornfels, Kristiania, Harz, Comrie (Goldschmidt, Erdmannsdörffer, etc.).
2. Cordierite quartz andalusite . .	Common Hornfels.
3. Cordierite andalusite spinel . .	Hornfels, Harz, Cornwall, etc. (Erdmannsdörffer, Flett, etc.).
10. Spinel enstatite cordierite . .	Hornfels, Comrie (Perthshire).
11. Spinel enstatite forsterite . .	In four-component system in basic igneous rocks.
6. Periclase spinel forsterite . .	Thermally metamorphosed dolomites.
7. Corundum spinel andalusite . .	Aluminium oxide rocks (Group XII), Hornfels, Ben Cruachan (Teall).
8. Corundum cordierite andalusite .	Hornfels, Comrie (Perthshire).
9. Corundum cordierite spinel . .	Hornfels, Adamello, Mt. Ascutney, Comrie. (Salomon, Daly, etc.)

The relation of the corundum, spinel, and enstatite bearing hornfelses to the more common free silica hornfelses, in the classification laid down by V. M. Goldschmidt, is evident at a glance, from the diagram Fig. 2, e.g. hornfelses of Classes (1) and (2) of Goldschmidt—in Fig. 2 represented by assemblage (2)—are represented by assemblages (3), (7), (8), (9).

Hornfelses of Class 3 (quartz plagioclase cordierite hornfelses) are represented by plagioclase cordierite spinel or plagioclase spinel hornfelses.

Lastly, hornfelses of Class 4 (quartz plagioclase cordierite enstatite hornfelses (1) in Fig. 2) are represented by assemblage (10).

Free Silica Hornfelses.	*Silica-poor Hornfelses.*
Class 1.—Andalusite Cordierite. Class 2.—Plagioclase Andalusite Cordierite. (Type 2 of Fig. 2.)	Assemblages, 3, 7, 8, 9. Corundum Spinel.
Class 3.—Plagioclase Cordierite. (Border Type 2/1 of Fig. 2.)	Plagioclase Cordierite Spinel. Plagioclase Spinel. (Border Type 10/3 of Fig. 2.)
Class 4.—Plagioclase Cordierite enstatite. (Type 1 of Fig. 2.)	Plagioclase enstatite cordierite spinel. Plagioclase enstatite spinel. (Type 10 of Fig. 2.)

Note on the Interpretation of the Wegener Frequency Curve.

By G. Vibert Douglas, M.Sc. (McGill) and A. V. Douglas, M.Sc. (McGill).

WEGENER bases his theory[1] of the drifting continents on the assumption that there are two distinct levels to be taken into account, the surface of the masses of "sal" which form the continents and the surface of the "sima" in which they float. His justification of this fundamental assumption appears to be based on the frequency curve obtained by measuring heights positively and depths negatively from sea-level, and plotting the frequencies[2] of such measurements as in Fig. 1. Because two maxima appear, Wegener draws the conclusion that therefore two layers must be considered as having been acted upon to produce the elevations and depressions of the earth's surface, and he implies that there would be but one maximum (Fig. 1, dotted curve) if only one layer were involved.

The questions which present themselves are whether the above conclusions are justified, or whether the frequency curve does not admit of an altogether different interpretation.

1. Consider what the frequency curve would be on the assumption of only one surface layer being acted upon to produce elevations and depressions. A perfectly symmetrical spherical surface or oblate spheroidal surface subjected to the horizontal and vertical forces producing diastrophism, would, if studied in vertical sections, probably show a wavy contour—a series of anticlinoriums and synclinoriums resembling a curve compounded of sine-curves of greater and less wave-length, the term "sine-curve" being used not in its strict mathematical sense, but descriptively, to imply that the general outline of the elevations would be represented by curves convex outwards and of the depressions by curves concave outwards[3] (Fig. 2). Constructing the frequency curve representing the systematic compilation of the data from all such vertical sections, the result could not differ essentially from Fig. 1, that is, it would show two distinct maxima. This is evident from the geometry of a true sine-curve (Fig. 3), which would give rise to a U-shaped frequency curve of heights and depths, unless accidental irregularities were superimposed on the sine curve producing "tails" to the frequency curve as in Fig. 1. Where the sine-curve is sloping

[1] A. Wegener: *Die Entstehung der Kontinente und Ozeane*, 2nd ed., 1920.

[2] Wegener expresses the frequencies as percentages of the total area of the earth's surface, and he adopts a vertical interval of 100 metres. Thus the frequency assigned to +1000 is the percentage of the earth's surface occupied by land between the 950 m. and 1,050 m. contours.

[3] It is not suggested that the profile of any given section of the earth (taken, for example, around a certain line of latitude) would be capable of being represented accurately by a Fourier Series; but it might probably resemble, in its main outline, a portion of the graph of some such series.

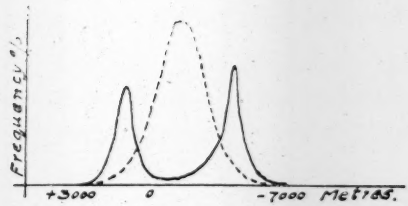


FIG. 1.

FIG. 2.

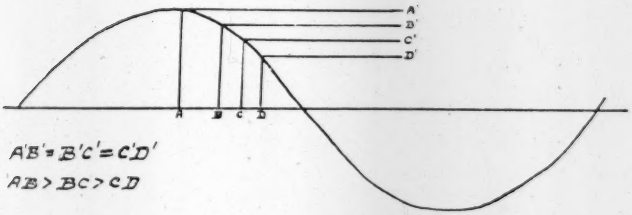


FIG. 3.

FIG. 4.

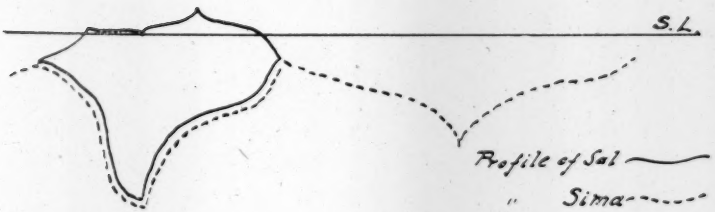


FIG. 5.

FIGS. 1–5.—The Wegener frequency curve and various profiles.

rapidly the frequencies are necessarily small, and where the tangent to the curve approaches the horizontal the frequencies are great; because the frequencies are proportional to the projections on the horizontal of elements of the curve cut off by parallel, equispaced, horizontal lines representing small equal increments of height, and these projections are greatest under those portions of the curve where the tangents are horizontal or nearly so. Hence one maximum occurs for heights and one for depths.

The frequency distribution obtained in the manner above described, would be in all essentials identical with that obtained from the Hypsometric Curve. (This curve, of irregular cusp form, should not be interpreted as representing a profile.)

It is thus shown that the fact of there being two maxima does not in itself preclude the idea of one surface layer only.

2. Consider, now, what type of contour of any representative vertical section would lead to a frequency curve showing only one maximum. This curve could only arise if the sectional contour were of the form of cusps (Fig. 4), regular or irregular, with the point of inflexion corresponding to the position of the maximum frequency. The general form of the curves on either side of the greatest elevations would then be concave outwards, and of the curves bounding the depressions convex outwards, in contrast to the case already considered. It should be noted, however, that unless this cusp contour were perfectly symmetrical the frequency distribution could not be a symmetrical curve as shown in Wegener's diagram (Fig. 1, dotted curve), but would be represented by some form of asymmetrical, single-maximum curve.

The case of the regular cusp contour may be dismissed at once as impossible. The case of an irregular cusp surface is certainly improbable. If land elevations were due solely to volcanic action, a contour of this nature might conceivably arise, but terrestrial forces other than volcanic are the predominant causes of continental uplift. Those portions of the land surface which present a cusp-like form owe their shape not to structural folding but to erosion, and in any case are insignificant compared with the main undulations of the earth's topography. What forces would lead to a contour of this kind in the depressions of the ocean floor it is difficult to imagine, if we except the highly improbable case of a gigantic "sink".

3. The hypothetical case of two definite layers falls into two classes, according as we assume a profile for each layer of the "sine-curve" type or of the "cusp" type. The former would certainly show two maxima, but not necessarily only two maxima, since it is quite possible that the "sal" would show two predominant frequencies, one representing the average elevations, the other the average depressions; and likewise the "sima". If, however, the "sal" and "sima" are actually one, then individual ups and downs are likely to be merely small effects, superimposed on greater

undulations, and the frequency curve smooths itself down to the inevitable two maxima.

The latter or "cusp" type might lead to a frequency curve of either one maximum or two. It would lead to two maxima, corresponding to the average points of inflexion of the surface of the "sal" and of the "sima", if and only if "sal" and "sima" were sufficiently distinct not to be merged in one general cusp profile on a larger scale embracing both (Fig. 5). In this latter case, only one maximum would be obtained. This possibility is suggested by the diagram given by Wegener in another connexion, showing the "sal" floating as an island in the "sima".

The writers are indebted to Mr. Philip Lake and to Mr. G. U. Yule for valuable advice.

The object of this note is (1) to show that Wegener's two-maxima frequency curve is capable of being interpreted in more than one way, so that the deduction which he draws from it, though not impossible, is certainly not conclusive; (2) to show that Wegener's single-maxima frequency curve cannot bear the interpretation which he puts upon it.

The Lithology of the Sodbury Section.

By Sidney H. Reynolds, M.A., Sc.D.

(PLATE III.)

CONTENTS.

I. Introduction.
II. Vertical section.
III. Summary of the rock characters from the stratigraphical aspect and comparison with those of the Avon section.
IV. Summary of the rock characters from the lithological aspect.
V. *Modiola* phases of the Sodbury section.

I. INTRODUCTION.

THE section of Carboniferous Limestone exposed in the railway cutting on the South Wales relief line to the west of Badminton station is a very fine one, being inferior in the Bristol district only to those of the Avon and of Burrington. There is a continuous section from high up in D_1 to the top of K_2.

Vaughan,[1] in his classical paper on the Palæontological Sequence in the Carboniferous Limestone of the Bristol area, gave a fairly full account of the lithology, and there is a brief account in the Mem. Geol. Surv. Summary of Progress for 1902, pp. 192–4.

Note.—The cost of preparation of rock sections, some 150 in number, examined in connexion with this paper has been defrayed by grants from the University of Bristol Colston Society.

[1] *Q.J.G.S.*, vol. lxi, 1905, pp. 204–11.

II. VERTICAL SECTION.

The Cleistopora Beds (K).
(Thickness about 390 feet.)

		feet.
	Km.	
1.	Mainly marly and sandy limestone, with calcareous grit. Some of the limestones contain ostracods . . . about	65
	α.	
2.	The Bryozoa-bed, red, crinoidal, and bryozoal limestone . .	10
	K_1.	
3.	Compact limestone with subordinate bands of calcareous grit and shale. At the base is the equivalent of the "Palate bed" of the Avon section, with teeth of *Psephodus* about	30 seen.
	(Gap of 165 feet almost devoid of exposures and representing the main part of K_1 and K_2.)	
4.	Shales with subordinate bands of crinoidal limestone. The upper beds include sandy and marly limestone and dolomite about	20 seen.

Notes on the Cleistopora Beds.

The lower part of the Bryozoa-bed is strongly banded and contains much sandy material and abundant ostracods.

Although a few small outcrops may be found, especially if the section be visited when the vegetation has died down, the exposure of K_1 is now practically confined to the lowest 30 feet and that of K_2 to the highest 20 feet.

The Zaphrentis-beds (Z).
(Thickness 275 feet.)

		feet.
	β and Z_1 (= 128 feet).	
5.	Mainly highly fossiliferous, but considerably dolomitized crinoidal limestone, but with occasional argillaceous bands and bands of pure dolomite	48
6.	In the main highly shattered and calcite-veined, unfossiliferous crinoidal limestone, but including bands of very fossiliferous crinoidal limestone	80
	Z_2 *and* γ (= 147 feet).	
7.	Massive, considerably dolomitized limestone full of crinoids and bands of brachiopods, with Zaphrentids prominent in the upper beds. Bands of unfossiliferous grey dolomite also present	147

Notes on the Zaphrentis Beds.

The *β* and Z_1 beds begin under Kingrove Bridge; 23 feet of band 5 are seen on the north side, while on the south side a thickness of 48 feet is exposed. The top of the shattered and veined limestone (band 6) is just east of the post marked 105.

Horizon *γ* teems with Zaphrentids, as it does in the Avon section. Foraminifera are plentiful at some levels, at others Bryozoa and *Palechinus* spines occur. Vaughan did not find any example of *Caninia* in the upper beds, and in consequence did not separate *γ* from Z_2. In the course of the present work a single example was found a few feet from the top of band 7.

The Syringothyris Beds (C).
(Thickness 422 feet.)

C_1 (*a*) *The laminosa-dolomite* (= 184 feet).

	feet.
8. Grey dolomite, very uniform in character and with little shale	160
9. Much weathered highly crinoidal limestone, partly dolomitized with a band (suboolite bed), crowded with *Orthotetes* and *Chonetes* at the base	4
10. Compact grey dolomite	20
C_1 (*b*) *The Caninia-oolite* (= 65 *feet*).	
11. Massive white oolite, sometimes showing current bedding	65
C_2 *The Caninia-dolomite* (= 174 *feet*).	
12. China-stone, often banded, and other types of calcite-mudstone, marly limestone, shale, and dolomite	113
13. Oolite	4½
14. Dolomitized china-stone in four bands, each of which grades upwards into shale with algal (*Spongiostroma*) nodules	13½
15. Grey china-stone weathering white with shale, marl, and dolomite	27
16. Massive grey limestone	3
17. White china-stone, often strongly banded with marly layers and dolomite	13

Notes on the Syringothyris Beds.

The whole series (band 8) below the suboolite bed is completely converted into fine, grey dolomite, in which all fossils are obliterated except some of the crinoid ossicles.

In its laminated and sometimes current-bedded character the *Caninia*-oolite resembles the equivalent rock at Tytherington. The *Caninia*-dolomite (C_2) forms the most typical example of a calcite-mudstone series seen in the section, all the various rock-types being exhibited to perfection.

Band 14 forms the most remarkable algal development in the section with the exception of the "Concretionary beds" of S_2 (d).

The dolomites were in the main originally china-stones. Several of the bands of calcite-mudstone show patchy development of penecontemporaneous brecciation.

The Seminula Beds (S).
(Thickness 574 feet.)

S_1 (=118 feet).

	feet.
18. Shale in part calcareous	23
19. Shale with marly limestone and thin bands of calcareous grit	19
20. Strongly laminated calcareous grit with algal nodules	1½
21. Shale with marly and gritty bands	12½
22. Massive grit sometimes coarsely quartzose	13
23. Variable series, including china-stone, sometimes algal, oolite, pisolite, thin dolomite, shale, and, near the base, calcareous grit	49
S_2 (= 456 *feet*).	
S_2 (*a*) (= 75 *feet*).	
24. Shale	1
25. Foraminiferal, oolitic, and bryozoal limestone (sometimes partly dolomitized), with *Seminula* bands and shaly partings	74

		feet.
	S_2 (*b*) (= 78 *feet*).	
26.	Massive limestone chiefly white oolite with bands of *Seminula*-pisolite and large masses of *Lithostrotion martini*	45
27.	Chiefly grey oolite moderately coarse in grain, but including bands and patches of china-stone and of foraminiferal limestone	33
	S_2 (*c*) (= 173 *feet*).	
28.	Dark, compact foraminiferal limestone, often slightly dolomitized with large masses of *Lithostrotion martini* and a few china-stone—*Seminula*—and pisolite bands; oolite begins to prevail at the base.	97
29.	Dark, compact foraminiferal limestone, often slightly and occasionally much dolomitized and including bands of oolite	76
	S_2 (*d*) (= 130 *feet*).	
30.	Variable limestone, chiefly dolomite and banded china-stone weathering white, and with some bands of *Seminula*-pisolite. Strongly marked "concretionary" (algal) bands and thick shale partings also occur, and some oolite is present	48
31.	Shale with two grit bands	6½
32.	Oolite	2
33.	Compact limestone, mainly china-stone and dolomite, with two "concretionary" (algal) bands. Includes also a band of oolite and two shale partings	19
34.	Shale with strong bands of grit, often ripple-marked	44½

Notes on the Seminula Beds.

S_1. All the various rock-types of the calcite-mudstone series are admirably seen in S_1. While some of the china-stones are algal, others are foraminiferal or ostracodal. Some of the algal (*Spongiostroma*) layers have an undulating surface exactly comparable to those seen [1] in S_1 of the Avon Section.

There is a well-marked band of *Seminula*-pisolite and, as is sometimes the case also in the Avon Section, the central portion of some of the pisoliths is replaced by crystalline calcite.

Some of the china-stones are composed of minute patches of dark, structureless limestone such as those figured [2] and described in the author's paper on the Lithological Succession of the Carboniferous Limestone at Clifton. One band is full of *Productus* spines, and is comparable with the *longispinus*-bed [3] of the Avon Section.

S_2. A strong band of *Lithostrotion martini* 10 yards east of the stream conduit is taken as the base of S_2 (c). The "concretionary" bands of S_2 (d) mainly consist of *Spongiostroma*, but may be partly composed of *Mitcheldeania*.

THE DIBUNOPHYLLUM BEDS (D).
(Thickness seen 84 feet.)

		feet.
	D_1	
35.	Strongly oolitic and fossiliferous limestone	28
36.	Rubbly oolitic limestone enclosing masses of pebbly grit	10
37.	Limestone mainly white and foraminiferal, but in part oolitic, passing down into non-oolitic limestone, with corals abundant, especially in two shaly partings	46
	Total thickness seen	1,745 feet.

[1] See fig. *Q.J.G.S.*, vol. lxxvii, 1921, pl. ix (1).
[2] Ibid., pl. x (4), and p. 225.
[3] Ibid., pl. x (5).

Notes on the Dibunophyllum Beds.

The pebbly grit occurs not as a continuous band, but in the main as more or less rounded masses from 18 inches to 3 feet in diameter. These masses are arranged with their long axes roughly parallel to the bedding and are completely surrounded by limestone which, as has been already pointed out, is oolitic and sometimes rubbly. Crinoids and other fossils are generally abundant in it. The gritty masses appear to be always sharply defined from the limestone, as is well brought out if a junction specimen is treated with HCl. The quartz pebbles in the grit may be an inch long, but this is quite exceptional. Sections show the grit to be clearly detrital in character, being formed of angular and rounded quartz grains embedded in a matrix formed in the main of finely divided quartz, but containing much carbonate of lime, as is seen on treatment with HCl. The limestone surrounding the grit may contain abundant detrital quartz, and flakes of muscovite occur both in the grit and in the surrounding limestone.

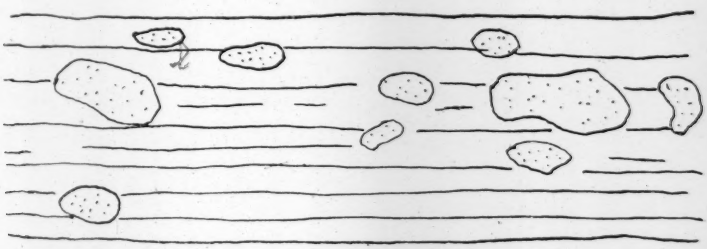


FIG. 1.—Diagram showing a portion of band 36 in the foregoing section. The grit masses are dotted. The thickness of band 36 is 10 feet.

One possibility with regard to these grit masses is that they may be infillings. This is suggested by (1) their sharply defined boundaries; (2) the fact that they contain in places rounded quartz pebbles which may reach the length of an inch; (3) the fact that examination with a hand-lens and of a limited number of sections has not shown the presence of any organic remains.

On the other hand, the masses are so numerous and are distributed through such a considerable thickness of rock (10 ft.) that it is scarcely possible that there could be no trace of piping down from the surface had it occurred. A further point against the view that they are due to infilling is their tendency to be elongated parallel to the bedding planes. The presence of flake of muscovite, both in the grit masses and surrounding oolite, is significant, as is the frequent abundance of detrital quartz in the oolite.

On the whole, it seems probable that they are in part the result of local deposition of excess of sandy material, in part are due to a subsequent process of segregation leading to the removal of the calcareous matter from these relatively sandy patches.

They are certainly in no way related to the quartz-rock described by Bemrose [1] from the Carboniferous Limestone of Derbyshire, as this is clearly due to crystallization.

No typical pseudobreccias are seen in the Sodbury section, though the rubbly character of part of the oolite enclosing the grit masses is probably due to a recrystallization process leading to a separation of the argillaceous material.

III. SUMMARY OF THE ROCK-CHARACTERS FROM THE STRATIGRAPHICAL ASPECT AND COMPARISON WITH THE AVON SECTION.

(1) The Cleistopora Beds.

The Modiola shales (K_m). The beds consist of sandy and marly limestone and calcareous grit with a little fine dolomite. They are less calcareous than those of the Avon section, and algal bands, so characteristic of that section, were not observed. The exposures are now very bad.

The Bryozoa Bed (*a*) is a ferruginous bryozoal and crinoidal limestone identical in character with that of the Avon Section.

K_1 *and* K_2, now very poorly exposed, consist of shales alternating with bands of highly fossiliferous limestone and a little dolomite. A band with fish-teeth at the base of K_1 is identical with the "Palate-bed" of the Avon Section.

(2) The Zaphrentis Beds.

The whole series is mainly crinoidal limestone identical with that of the Avon. The matrix, as in the Avon rocks, is usually converted into a mass of conspicuous dolomite crystals, while the crinoids and, to a less extent, the corals and brachiopods are little affected. In γ–Z_2 and the lower part of Z_1 are bands completely converted into dark, structureless dolomite. Such bands, though occurring in Z_1 of the Avon Section, are not met with in γ and Z_2. Bands of brachiopods are more conspicuous and Zaphrentids are somewhat less conspicuous than in Z_2 of the Avon Section.

The Sodbury development also differs from that of the Avon in that no chert band has been observed in Z_1, that there are no fish-beds at the top of Z_2, and in the shattered and veined character of upper Z_1.

(3) The Syringothyris Beds.

C_1 (a). The *laminosa*-dolomite consists of crinoidal limestone completely converted into fine, grey dolomite. A band with *Orthotetes* and *Chonetes* exactly similar to the Suboolite-bed of the Avon and other sections occurs, but, instead of being at the top of the dolomite, is situated about 20 feet below the top.

C_1 (b). The *Caninia*-oolite closely resembles that of the Avon Section, but is somewhat less regular and conspicuous. In places it shows current-bedding.

[1] *Q.J.G.S.*, vol. liv (1898), pp. 169–83.

C_2 The *Caninia*-dolomite. This consists of marly bands, china-stones often laminated and as a rule much dolomitized, oolites, and shales. A layer of algal nodules is a conspicuous feature of the middle part of the series.

(4) The Seminula Beds.

S_1.

S_1 consists of a lower series largely composed of shale and grit and an upper series of thin-bedded china-stones sometimes algal, oolite, and pisolite, all more or less dolomitized. A massive band of grit separates the two series.

The rocks differ from those of the Avon in their relatively more shaly and gritty character and in the absence of large masses of *Lithostrotion martini*.

S_2.

S_2 (a), as in the Avon Section, consists largely of massive limestone partly dolomitized and with *Seminula*-pisolite layers. The Sodbury limestone is, however, far more oolitic than that of the Avon Section, and the bands of chert seen near the top of S_2 (a) in the Avon Section are not met with at Sodbury.

S_2 (b), the *Seminula*-oolite as in the Avon Section, is mainly white or grey oolite, but china-stones and *Lithostrotion* limestone are more prevalent. As in the Avon Section, the *Seminula*-oolite weathers rapidly and soon becomes ill-exposed and overgrown.

S_2 (c). The rocks of this level are nearly identical with those of the Avon section, and consist chiefly of massive limestone, often foraminiferal, with abundant *Lithostrotion martini* and a few china-stone and pisolite bands.

S_2 (d). This level is very thick in the Sodbury section. The rocks consist of an upper series of shales and grits unrepresented in the Avon Section and a lower series of concretionary (algal) bands with china-stone and pisolite and one massive grit band. The limestones throughout are more or less dolomitized.

(5) The Dibunophyllum Beds.

D_1. The lower beds are mainly oolitic, but at the top is a remarkable layer of limestone enclosing large, rounded masses of pebbly grit. The upper beds are mainly highly foraminiferal and coral-bearing white limestone.

Except for the occurrence of the pebbly grit masses and the poor development of pseudobreccias, the succession is much like that of the Avon. The section ends below the equivalent of upper D_1 of the Avon Section.

IV. Summary of the Rock Characters from the Lithological Aspect.

(a) Calcareous Rocks.

Algal Limestones are less conspicuous than in the Avon Section. They have not been recognized in K_m, but form a very marked

development in C_2 and occur in S_1. The concretionary algal limestone of upper S_2 is very finely developed, and the *Seminula*-pisolite bands of S may be alluded to under algal limestones. In the middle of C_2 layers of *Spongiostroma* nodules occur, and in S_1 *Spongiostroma* occurs in undulating sheets as in the Avon Section. In the "Concretionary beds" *Spongiostroma* prevails, but *Mitcheldeania* is also met with. Patches apparently of *Girvanella* occur in D_1 and S_1.

Foraminiferal Limestones. The distribution of foraminifera is much as in the Avon Section. They first begin to be fairly common in Z_2, are abundant in the *Caninia*-oolite, often forming the centre of the grains, and are seen frequently at successive levels in C_2 and the whole of S. *Rotalia* and *Endothyra* are the commonest forms. *Textularia* appears to be commoner than in the Avon Section.

Calcisphaera occurs at numerous levels in the D, S, and C beds.

Coral Limestone. Zaphrentids teem in the upper part of Z_2 and γ. Bands of *Lithostrotion martini* are characteristic of S_2 (c). As is the case throughout the S.W. Province, corals are very plentiful in D_1.

Crinoidal limestone is, as in the Avon Section, characteristic of almost the whole *Zaphrentis* zone and, as far as can be ascertained from the poor exposures, also of K_2. The *laminosa*-dolomite seems to have been originally in the main a crinoidal limestone. Sections of echinid spines, presumably to be attributed to *Palechinus*, occur at various levels from D_1 to Z_1.

Brachiopods rival crinoids as limestone builders throughout Z_1, *Chonetes hardrensis* and *Spirifer clathratus* being, as in the Avon Section, the most abundant forms. *Seminula* bands are characteristic of S_1, *Productus*, and *Chonetes papilionacea* bands of S and D.

Bryozoa are abundant at intervals from D to the Bryozoa-bed (a). They seem equally plentiful in standard limestones and in limestones formed under "*Modiola*-phase" conditions. They are probably more abundant than in the Avon Section.

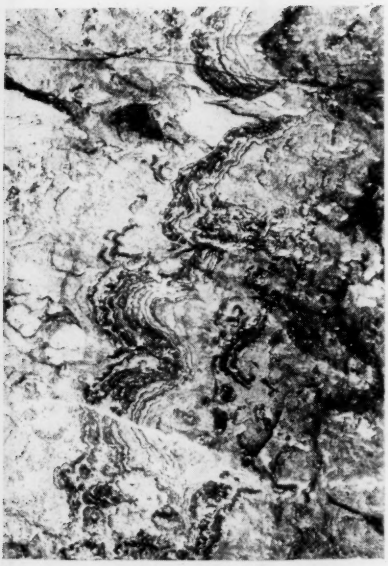
Fish. Vaughan records abundant (Elasmobranch) teeth in the "Palate-bed" (base of K_1) and states that similar teeth are found less frequently in the overlying beds for a considerable distance.

Oolites occur: (1) in upper C_1 the *Caninia*-oolite; (2) there is a band in the upper part of the *Caninia*-dolomite (C_2); (3) *Oolites* are plentiful from the top of S_1 to the base of S_2 (c), and are specially prevalent in S_2 (b), the *Seminula*-oolite; (4) There is a good deal of oolite in the "Concretionary beds" S^2 (d); (5) Coarse oolites are characteristic of D_1.

(b) Siliceous Rocks.

Grits play a far more important part in the *Seminula* beds than they do in the Avon Section. There is a band 13 feet thick in S_1 and grits are very conspicuous in upper S_2 (d). No cherts have been found in the Sodbury section.

2



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3

(c) Argillaceous Rocks.

Shales are more important than in the Avon Section. They occur: (1) in the *Cleistopora* beds; (2) in C_2, where they are relatively unimportant; (3) in lower S_1, where they are very thick; (4) in the upper part of S_2 (d).

V. MODIOLA PHASES OF THE SODBURY SECTION.

The three "*Modiola*-phases" represented in Gower [1] and the Avon Section [2] occur also in the Sodbury section. Comparing the Sodbury development with that of the Avon, it may be noted:—

First Modiola Phase (K_m). The Sodbury development, which is less calcareous than that of the Avon, agrees with it in the non-occurrence of conglomerates or oolites.

Second Modiola Phase (C_2 and S_1 (a)). The rocks differ from those of the Avon Section in including a considerable amount of grit and in the fact that the standard limestones which interrupt the continuity of the *Modiola* phase rocks in the Avon Section are not represented at Sodbury.

Third Modiola Phase (S_2 (d)) includes less standard limestone than in the Avon Section, but more grit and shale.

DESCRIPTION OF PLATE III.

Fig. 1.—Weathered surface of "concretionary" (algal) limestone, S_2 (band 30), west of Lilliput Bridge, Sodbury section. Length of part shown about 3 feet.

Fig. 2.—Part of the same rock in section. × ½.

Fig. 3.—Shale with algal (*Spongiostroma*) nodules, C_2 (band 14), east of Lilliput Bridge, Sodbury section. The penny gives the scale.

Fig. 4.—Grit mass in rubbly oolitic limestone, D_1 (band 36), west of Lilliput Bridge, Sodbury section. The 2 ft. rule gives the scale.

A Boring in the Trias at Upton-on-Severn, Worcs.

By L. Richardson.

In 1906–12 a deep boring was made at Red Hill, Upton-on-Severn, to obtain water for the town of Upton. The boring was made by Messrs. E. Timmins & Co., Ltd., of Runcorn, for the engineers, Messrs. Willcox & Raikes, of Birmingham. The particulars as to the thickness, etc., of the Triassic rocks here are of considerable interest and I am indebted to Dr. J. Selwyn Cowley, of Upton on-Severn, for lending me Messrs. Willcox & Raikes' record of the rocks penetrated, which is as follows:—

[1] *Q.J.G.S.*, vol. lxvii, 1911, p. 514.
[2] Ibid., vol. lxxvii, 1921, p. 237.

BORING AT RED HILL, UPTON-ON-SEVERN.

Top of bore-hole: 160 ft. above ordnance-datum.

	Thickness. Ft.	in.	Depth. Ft.	in.
Soil	2	0	2	0
[Upper Keuper Marls.]				
1. Red marl	23	0	25	0
2. [? Upper Keuper Sandstone.] Hard grey marlstone	21	0	46	0
3. Red marl	27	0	73	0
4. Red and grey marl	66	0	139	0
5. Red marl with gypsum	32	0	171	0
6. Grey marl with gypsum	2	0	173	0
7. Red marl with gypsum	65	0	238	0
8. Hard red marl with gypsum	10	0	248	0
9. Red and grey marl	189	0	437	0
10. Dull red marl with gypsum	154	0	591	0
11. Grey marlstone	1	0	592	0
12. Red and light brownish and blue marl with signs of slips and fallen pieces of gypsum 13. Reddish-brown and bluish-grey marl with thin veins of gypsum, very broken	708	4	1,300	4
14. Fine reddish-grey sandstone		3	1,300	7
15. Reddish-brown marl	2	0	1,302	7
16. Reddish-grey marly sandstone		10	1,303	5
17. Reddish-brown marl with veins of gypsum		6	1,303	11
18. Reddish-brown marl	25	1	1,329	0
[? Keuper Sandstone.]				
19. Grey sandstone		5	1,329	5
20. Marly sandstone	1	0	1,330	5
21. Fine red sandstone		6	1,330	11
22. Reddish-brown marl	8	3	1,339	2
23. Coarse grey sandstone	1	9	1,340	11
24. Reddish-grey sandstone		9	1,341	8
25. Reddish-grey marl		6	1,342	2
26. Reddish-brown marl		9	1,342	11
27. Coarse grey sandstone	3	3	1,346	2
28. Reddish-brown marl	2	5	1,348	7
29. Reddish-grey sandstone	3	0	1,351	7
30. Reddish-grey sandstone (marly)	2	6	1,354	1
31. Reddish-brown marl	10	8	1,364	9
[Keuper Sandstone.]				
32. Reddish-grey sandstone	36	3	1,401	0
33. Grey shaly sandstone	2	0	1,403	0
34. Reddish-grey sandstone	9	9	1,412	9
35. Grey sandstone	1	0	1,413	9
36. Reddish-grey sandstone		9	1,414	6
37. Grey sandstone	3	6	1,418	0
38. Reddish-grey sandstone	34	5	1,452	5
39. Bluish-grey shale	14	3	1,467	8
40. Grey sandstone [*specimen in the Museum, Victoria Institute, Worcester*]	10	0	1,477	8
41. Reddish-grey sandstone	1	6	1,479	2
42. Greyish-white sandstone	1	3	1,480	5
43. Reddish-grey sandstone	4	0	1,484	5

		Thickness. ft.	in.	Depth. ft.	in.
44.	Reddish conglomerate	1	6	1,485	11
45.	Mottled sandy marl	3	0	1,488	11
46.	Reddish grey sandstone	4	0	1,492	11
47.	Mottled sandy marl	1	0	1,493	11
48.	Reddish-grey sandstone [*specimen in the Museum, Victoria Institute, Worcester*]	40	3	1,534	2
49.	Bluish-grey shale	5	6	1,539	8
50.	Reddish-grey sandy marl	23	6	1,563	2
51.	Reddish-grey sandstone with 3 in. of grey sandstone at bottom	50	9	1,613	11
52.	Reddish-brown marl, grey mottled (cores wasted away)	21	6	1,635	5
[53.]	[? Ditto]	64	7	1,700	0

		Ft.	in.		in.		in.	
Lined from	surface to	310	0	with	$13\frac{3}{4}$	× 13	s/s	tubes.
,,	289 ft. $6\frac{3}{4}$ in. below surface to	385	0	,,	$11\frac{1}{4}$	× $10\frac{1}{2}$	s/s	,,
,,	358 ft. ,, ,,	462	6	,,	$8\frac{3}{4}$	× 8	s/s	,,
,,	390 ft. $7\frac{3}{4}$ in. ,, ,,	952	0	,,	7	× $6\frac{3}{8}$	f/j	,,
,,	911 ft. 1 in. ,, ,,	1,152	0	,,	6	× $5\frac{3}{8}$	f/j	,,
,,	846 ft. 2 in. ,, ,,	1,528	4	,,	5	× $4\frac{3}{8}$	f/j	,,

Rest-level of water, 2nd May, 1913.—36 ft. 6 in. below surface level. During boring operations water was encountered at 60 ft. and 190 ft. down, but otherwise none was met with until the Keuper Sandstone was reached.

Unfortunately, I did not see the cores as they were drawn, but I was given pieces which were stated to be typical of beds 40 and 48 (above). That of bed 40 shows the rock to be a light greyish-green fine-grained sandstone, with inconspicuous specks of white mica and less frequently of black mica, while that of bed 48 a red, fine-grained sandstone, highly micaceous (principally flakes of black mica).

As regards the identification of the beds, there is again the difficulty that the cores were distributed before my attention was drawn to the boring.

Bed 2 may be the Upper Keuper Sandstone. It is difficult to decide where to draw the line of demarcation between Keuper Marls and Sandstone; probably it had better be regarded as coming between beds 18 and 19.

The Problem of Batholithic Intrusion.

By W. A. Richardson, M.Sc., B.Sc. (Eng.), F.G.S.

I. Thermal Stoping.

SPECULATION as to the causes of the great intrusions known as batholiths is coeval with petrology as a science. Daly says that batholiths are "the least understood of all the intrusive bodies. If they were truly understood there would be no 'problem' of the igneous rocks".[1] This, no doubt, puts the matter too strongly, but there is nevertheless much truth in the statement,

[1] R. A. Daly, *Igneous Rocks and their Origin*, New York, 1914, p. 89.

and the "problem" is of the greatest importance in petrogenic theory.

The statement of the problem in its clearest form is distinctly a debt that petrology owes to Daly. The essential features of these extraordinary rock-bodies, that call for explanation, have been summarized by him along the following lines :—[1]

1. *Occurrence in space* in orogenic belts and elongated in the direction of the tectonic axis : *in time* following more or less closely an *antecedent* period of orogenic movement. (It is important to note, however, that batholiths are not revealed in *every* mountain chain.)

2. *Form.* A roof irregularly domed ; walls relatively smooth and steeply inclined ; the whole enlarging downwards and without a visible floor.

3. *Attitude* replacive towards the invaded formation and not, as in the case of laccoliths, displacive.

4. *Composition* remarkably uniform and generally of a granitic character.

Contemplation of these facts, which, I suppose, most workers accept, shows that these bodies have definite, and in many respects amazing, characteristics indicating a mechanism of intrusion differing from that of other intrusive bodies.

Of the explanations that have been advanced some, e.g. the cavity theory of Suess, are of historic interest only ; whilst others, such as the marginal-faulting hypothesis of Iddings, apply to individual intrusions, and must be judged on the merits of the special case. The marginal assimilation hypothesis of Lévy and Lacroix has been destructively criticized by Harker. Brögger regards batholiths as laccoliths disguised by irregularities, but to dismiss the unique characters of the bodies as "irregularities" seems to me to beg the question. Daly himself has advanced, so far as I am aware, the only comprehensive theory to cover all the aspects of the question as stated by himself ; and it is with his views that this paper is, in the first place, concerned.[2]

Daly's petrogenic theory is comprehensive, so we may proceed to abstract—I hope with all fairness—those elements pertinent to our present inquiry, namely the intrusive mechanism of batholiths. For full details the reader is referred to the *Igneous Rocks and their Origin* and the numerous papers of Daly which are cited in this volume. The essential points are as follows :—

1. Besides the external sedimentary covering, a gravity stratification of the earth's crust into shells is postulated, of which two only concern us, namely an outer acid and, immediately beneath it, a basaltic layer.

[1] Ibid., chap. vi.

[2] For general summaries see : A. Harker, *Natural History of the Igneous Rocks*, Lond., 1909, chap. iii ; J. Barrell, "Marysville Mining District (Montana)" : *U.S. Geol. Surv.*, prof. paper, No. 57, 1907, p. 151 et seq.

2. Relief of strain, deep-seated in the crust, gives rise to an *abyssal fracture up which a wedge of primary basalt is injected.* This also is of the nature of a postulate, though based on cosmogenic considerations, and is, as will appear, the basis upon which the whole theory ultimately rests.

3. Partly because of crustal collapse and partly because of outflow of basalt, a widespread sinkage takes place, giving rise to a geosynclinal. Sedimentation and rise of isogeotherms initiate mountain-building, in accordance with the classical theory. Abyssal injection, then, combined with crustal collapse, accounts for the position of batholiths in belts of orogenic disturbance.

4. The abyssal injection works its way upwards by absorption first of the acid shell and later of the sedimentary covering. Primary heat in the abyssal wedge accounts for the assimilation, whilst differentiation of the syntectic so formed yields a granitic magma.

5. The progression of the magma into the upper reaches of the earth's crust, i.e. among relatively cold and solid rocks, takes place by *magmatic stoping.* The heated magma shatters the contact belt, which falls in and presents a new surface to the action of the magma. This progress is advanced to explain the replacive attitude and, presumably, the form of the batholithic chamber.

6. Since obviously it takes time for the abyssal wedge to work its way upwards, orogenic crumpling should be nearly completed before visible contacts are established. Therefore, the lagging of intrusion behind movement is accounted for.

Before passing to criticize this theory it should be noted that, after initial crustal failure, the motive power is mainly thermal.

Moreover, this theory presents a great initial difficulty in the binary origin of granite. Why, if we allow Daly's primary postulate of an acid shell—and there are reasons why we should do so—are we called upon to believe that actual granite is this primary material returned after a complex process of assimilation and differentiation? Why must we believe that pre- and post-Cambrian granites that show no essential petrographic differences yet originated differently? The obvious reason is the necessity of accounting for the complete disappearance of the basalt and a recognition of the fact that if there is sufficient heat to allow of the continuous operation of magmatic stoping there must be sufficient to account for assimilation. It is in view of such considerations that Daly considers assimilation a necessary corollary of magmatic stoping. Daly's case, indeed, would be more compact, and therefore stronger, if only a basaltic shell had been postulated and then the granite derived from it by assimilation of sedimentary material. This view is, however, ruled out by the difficulty of finding sediments to account for the earliest granites. Meanwhile, only the strongest necessity could justify the petrologist admitting a plurality of causes of this nature to account for the origin of so common a rock as granite.

The thermal and chemical difficulties of the theory have been dealt with by others, especially Harker,[1] including the facts of chilled margins. In spite of much ingenuity, the reply to these criticisms seems to me far from convincing. But, whether it be so or no, my object here is to advance fresh criticism rather than revive the old.

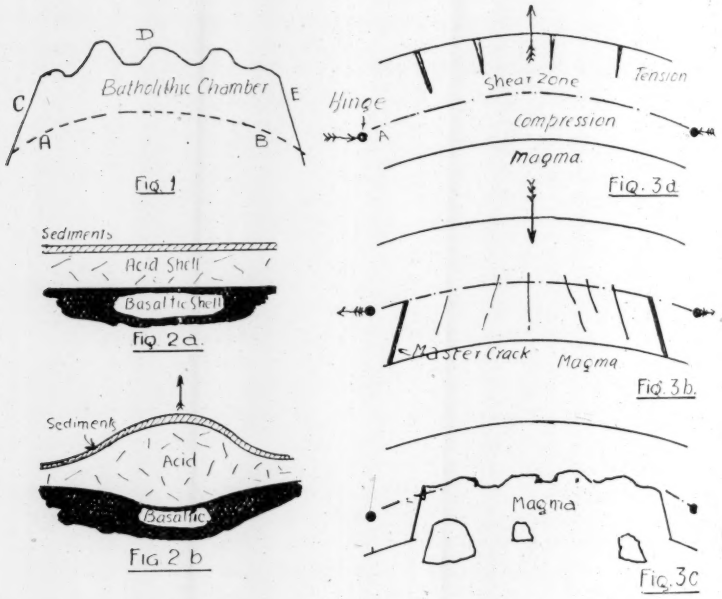

FIG. 1.—Ideal form of batholithic chamber (after Daly).
,, 2*a*.—Crustal stratification before disturbance.
,, 2*b*.—Concentration of light (granitic) material beneath a zone of orogenic uplift (initial batholithic stage).
,, 3.—The establishment of "visible contacts" (i.e. the final batholithic stage).
(*a*) Stress conditions during uplift of a thick simple arch. (*b*) Reversal of stresses following slight downward oscillation. Master cracks formed near arch-hinges. (*c*) Form of batholithic chamber due to mechanical stoping.

The first question that suggests itself is whether magmatic stoping can really be regarded as a probable cause of the *form* of the batholithic chamber. One process of the kind open to observation is that which has been variously called *exfoliation* or *squamation*. This effects, not the detachment of blocks, but, even in massive rocks, a scaling off of layers, giving ultimately a more or less gently curved surface. In fact, the resulting surface would

[1] Op. cit.

more probably be some such shape as that indicated by the dotted line, AB Fig. 1, rather than the characteristic surface established by Daly, and indicated in simplified form by the full line, CDE Fig. 1.

Secondly, exfoliation is due to *alternating action*, i.e. to expansion and contraction caused by alternately heating and cooling the surface attacked. Any such alternation seems excluded from magmatic intrusion by the nature of the case. Moreover, Daly has emphasized the relative slowness of the uprise compared with orogenic processes, and this must mean that sufficient time is available for a heating of the rocks ahead of the seat of intrusion. In other words, the intruding magma establishes a thermal gradient in the rocks above it, which progressively advances as the intrusion climbs higher and higher in the crust. Hence, if slow advance is a fact, then no opportunity for the sudden heating of the contact rock is likely to be provided. Hence it may be concluded that the existence of conditions necessary to produce exfoliation is improbable; and that even if the process operates it is unlikely to produce the peculiarities of the shape of the chamber.

The other view, that the roof is cracked as a glass by hot water, is *a fortiori* excluded, because heating still more sudden is required. Moreover, the vertical cracks of Daly's diagrams are hardly possible, since he supposes—and rightly—that the chamber roof is under lateral compression.

Now, since batholiths are associated with orogenic regions and movements, it is clear that theories of their origin must not only take account of their own characters, but must at the same time harmonize with any facts peculiar to mountain districts. A body of such relevant fact is that upon which the theory of isostasy rests and which has revealed the relation existing between crustal density and topographic relief. To quote Barrell: "over broad, high areas the mean elevations are high *because* the crustal densities are there low; and, *vice versa*, the mean surfaces of low areas are low *because* the densities there are high."[1] From the standpoint of orogenic uplift, Oldham interprets this condition as indicating that mountain building is accompanied by a sub-surface flow of lighter material beneath the area, *accompanied by a downwarp of the crust and a displacement of the lower heavier substratum.*[2] Finally, it may be pointed out that geodesists in their calculations employ 2·8 as the density of the lighter material, i.e. the density of acid igneous rocks; and 3·3, the density of heavy basalt, for that of the heaviest material that can in the light of knowledge be postulated in the "heavier substratum".

Daly's hypothetical process of the injection of an abyssal basaltic wedge is just the reverse of that deduced by Oldham from geodetic

[1] J. Barrell, "The Status of the Theory of Isostasy": *Amer. Journ. Sci.*, 1919, vol. xlviii, p. 292.

[2] R. D. Oldham, "Support of the Himalayas": *Abs. Proc. Geol. Soc.*, 1916, No. 985.

data. The former is primarily characterized by the initial inflow of heavier material, and the latter by its outflow. If it be objected that the abyssal material would expand on attaining a level of lesser compression, it may be pointed out that the densities employed are those of *surface* rocks, and that it is unlikely that the primary basalt would assume a lower density than this. Whatever allowance is made, we certainly possess no facts relating to the expansion of primary basalt that would give any support to the "tumefaction" hypothesis of mountain uplift. The introduction of the abyssal wedge must, until strong evidence to the contrary is produced, be regarded as increasing the mean density of a unit column at the site of injection. It would seem that if the facts leading to the hypothesis of isostasy be true, they are fatal to Daly's fundamental hypothesis of the abyssal injection of primary basalt.

II. Mechanical Stoping.

I shall now pass on to suggest in outline only an alternative explanation based entirely on mechanical considerations, and attempt to harmonize petrological data with isostatic requirements. Since this is not a fitting opportunity to review critically rival theories of isostasy, I shall restrict myself as much as possible to what is considered common ground, but, if theoretical interpretations of the data are required, shall make use of the flotation hypothesis of mountain building.

A. General.

1. The primary stratification of the earth's crust into two shells, an outer granitic and a lower basaltic, is postulated (Fig. 2a). This assumption is not entirely gratuitous, and the evidence has been summarized elsewhere.[1]

2. Mountain-building is interpreted petrologically as a concentration of this granitic material beneath the orogenic region, as in Fig. 2b. This is merely another way of stating Oldham's conclusion, but it accounts for the general presence of acid rocks beneath a mountain region.

3. Uplift in the centre of the region, as indicated by the arrow in Fig. 2b, means a relief of pressure over that region and so provides what Dr. Harker has shown to be the only necessary condition of liquifaction.[2]

B. Special.

A hint aiding the formation of a working hypothesis to explain the special features of batholiths is also obtained from geodetic observations. Oldham has pointed out that in the Himalayas parts are over-compensated, whilst others are under-com-

[1] W. A. Richardson, "The Frequency-Distribution of Igneous Rocks, II": *Min. Mag.*, March, 1923 (in the press).

[2] Op. cit., p. 37.

pensated.[1] Thus, in some places, the movement has been overdone and as though the uplifted masses had been carried further by their momentum. Up to a point, excess load can be supported by the strength of the rocks, but the facts may be taken to indicate the possibility of slight vertical oscillation after the first great upward movement has been brought to an end. I shall now attempt to show that such a slight oscillation would be a sufficient cause of the intrusion of the batholith into the upper crust and of the peculiarities of its " visible contacts ".

1. Consider the case of a thick, simple arch, resting on a fluid substratum below and gradually undergoing uplift in the direction of the arrow, Fig. 3a. The upper part of this arch is in tension, and cracks may appear, and the lower part is compressed. Along the arch line AB, or rather over a belt along this line, intense shearing forces are called into action.

2. Now suppose after the main movement has ceased reaction sets in, causing a slight downward movement in the direction of the arrow, Fig. 3b. Stress conditions are reversed ; the upper part is compressed, and the many cracks close ; the lower part is in tension, and the direction of the shearing forces is reversed. The greatest lateral movement is in the neighbourhood of the hinge, and the most pronounced cracks will open there. The reversal of the shear will favour horizontal fracture along the shear belt. These fractures will shatter the whole of the lower portion of the arch, and the detached blocks will fall in (Fig. 3c), but a relatively thick arch, supported on a fluid substratum, and suffering only a relatively small return motion will not collapse as a whole.

The conditions here outlined in a simplified way are consistent with the detailed features, whilst the collapse of the under surface accounts for the intrusion of the magma into the upper crust.

(*a*) The steep, smooth sides of the chamber represent the prominent boundary-cracks near the arch-hinge.

(*b*) The irregularly-domed roof coincides with the central shear belt.

(*c*) The *time* of intrusion must post-date the main uplift, for it is contingent on a slight settlement following the principal uplift.

(*d*) The attitude of the intrusion towards the invaded strata is replacive, not, as in the case of laccoliths, displacive.

(*e*) The explanation is in harmony with exceptions to the rule that batholiths are visible in mountain chains, for there is no reason why effective settlement should occur in every case.

(*f*) The curious observation by Daly, that they are most frequent in areas of greatest crumpling, would appear to agree with the expectation that where the movement has been most intense reaction is most likely to follow.[2]

[1] R. D. Oldham, " Structure of the Himalayas ": *Mem. Geol. Surv. Ind.*, Pt. 2, 1917, p. 114 et seq.

[2] Daly, op. cit., pp. 91–2.

(*g*) Finally, the difficulties of abyssal injection, thermal stoping, assimilation, chilled phases, etc., are avoided.

There is no necessity to assume the assimilation of the sunken material; and assimilation can only be proved to have occurred where it has left evidence in the mineral and chemical composition of the rock. A case in point is furnished by the granites of Cornwall, and most petrologists would ascribe these effects to the known richness of these magmas in mineralizers, rather than to excessive temperature.

REVIEWS.

CRYSTALLOGRAPHY AND PRACTICAL CRYSTAL MEASUREMENT. By A. E. H. TUTTON, D.Sc., F.R.S. Second Edition. In two volumes. Vol. 1: Form and Structure. pp. xvii+746+xiv. Vol. 2: Physical and Chemical. pp. vii and 747 to 1446. London: Macmillan and Co., Ltd., 1922. 50*s*. net, each volume.

SINCE its first appearance in 1911 Dr. Tutton's work on practical crystal measurement has been widely recognized as a comprehensive guide to the methods to be followed in making a complete morphological and optical examination of a crystal, and the appearance of a new and greatly enlarged edition in two volumes will arouse interest in many quarters. The elementary student will find his wants catered for by the reproduction, substantially unaltered, of the very detailed directions for measuring crystals with the ordinary one-circle goniometer contained in the first edition.

More advanced workers and those chemists and physicists whose investigations bring them in contact with crystals will turn to the new chapters where the startling developments of the last ten years are recorded, and will find therein admirably clear and up-to-date accounts of crystal structure as revealed by X-ray analysis as well as of the results obtained in the same field from purely geometrical considerations. These matters are dealt with in the first volume. The second volume is mainly devoted to the optical characters of crystals, and opens with an introduction containing much interesting information on a variety of matters which the title of the book would hardly lead us to look for within its pages. The description of the Michelson echelon and the Zeeman effect, and the chapters devoted to the thermal, elastic, and electrical properties of crystals, will appeal mainly to physicists, while chemists may study with profit the pages in which Isomorphism, Polymorphism, and kindred topics are discussed.

Although mainly concerned with the study of the optical characters of isolated crystals, all the methods of proven value now used for the determination of these characters from the examination of thin sections alone are adequately described and explained, and the student of Petrology will find these chapters an admirable introduction to the study of more purely technical works on the optical properties of rock-forming minerals. The one fault of the book, if fault it be, is that in his zeal to show how Crystallography has contact with a great variety of other branches of Science the author has attempted to survey a larger field than can be comfortably contained within the limits of a single treatise. The result has been two large, handsome, profusely illustrated volumes, but costly far beyond the means of the average student, for whom, to judge from

the fullness and detail of the explanations, they would seem chiefly to have been written.

A. H.

Die Mineralien der Südnorwegischen Granit-Pegmatitgänge II. By W. C. Brögger, J. Schetelig, and Th. Vogt. Vid. Selsk. Skr. 1, M.N.Kl, No. 1, 1922. pp. 1–151, with 15 plates.

THE appearance in print, after a lapse of sixteen years, of the second part of the studies devoted to the rarer minerals of the granite pegmatites of Southern Norway will be heartily welcomed by all mineralogists and petrologists.

Professor Brögger, in the first part (1906), dealt with the niobate, tantalate, titanate, and titanoniobate mineral types. The second memoir is largely devoted to a description of the minerals of the rare earths, yttrium, erbium, cerium, and scandium.

Brögger contributes to this memoir a discussion on the twinning laws of hellandite, the lime-alumina-yttrium-erbium silicate first described by him in 1903.

Th. Vogt investigates the properties of thalenite, the yttrium silicate; and J. Schetelig deals with thortveitite, gadolinite, kainosite, and orthite. Thortveitite was first noted by Schetelig in 1911, but a more detailed examination has enabled him to correct the crystallographic data and further the knowledge of its forms. This mineral is closely related to thalenite already mentioned, but is remarkable for its high content of scandium (40 per cent Sc_2O_3).

Thortveitite itself never shows a development of an amorphous alteration product such as is common to other rare earth silicates as gadolinite, hellandite, orthite, etc., nor has it any abnormal radioactivity. Those rare earth silicates showing the characteristic amorphous alteration products are usually abnormally radioactive, and it seems clear that this change is connected with the passage of the alpha ray. The amorphous substance in some cases at least has the same composition as the original anisotropic mineral, as for example in the case of gadolinite. The unaltered state of thortveitite is thus explained, but where radioactive minerals such as monazite or euxenite are included in it, alteration proceeds, forming narrow rings around the included minerals.

It is to be hoped that with such excellent material as has been obtained from these Norwegian pegmatites, the radioactivity of these minerals will be subject to a close examination, and, still more, that the minerals will be utilized by the Norwegian chemists and mineralogists to add further to our estimates of geological time by determinations of the lead-thorium, or lead-uranium ratios.

C. E. Tilley.

ESSENTIALS FOR THE MICROSCOPICAL DETERMINATION OF ROCK-FORMING MINERALS AND ROCKS IN THIN SECTIONS. By ALBERT JOHANNSEN, Ph.D. 4to. pp. 54, with folding table. Chicago, 1922.

THIS work seems to be intended to supersede the author's *Key for the Determination of Rock-Forming Minerals in Thin Sections*, published in 1908, in which the device of a thumb-index involved a great waste of space. The tables, however, have been rewritten, and there is additional material, such as brief notes on the mode of occurrence of the several minerals. By those who like the dichotomous or "key" method, the book will doubtless be found useful. The properties successively used in tracking down an unknown mineral are: opaque or transparent, isotropic or anisotropic, colourless or coloured, non-pleochroic or pleochroic, uniaxial or biaxial, negative or positive, and, finally, refractive index and birefringence, these last two being ingeniously presented together in a graphical scheme. Additional tests are provided where they are needed: thus, for discriminating the plagioclase felspars no less than twelve optical properties are plotted out as curves.

Some passages in the text are not very clearly expressed. For instance, the statement on page 31 that "only one kind of plagioclase of the same generation occurs in any igneous rock" seems at first sight at variance with the sentence preceding, while it is itself contradicted by the observation on zoned crystals which immediately follows. The notes on the mode of occurrence of the several minerals might, with advantage, be amplified. We find, for instance, under the garnet group no record of the occurrence of almandine in aplites and pegmatites, and the pyrogenetic melanite is not distinguished from the metamorphic andradite.

The book is presumably designed for the use primarily of the Professor's own students. It concludes with a brief exposition of the author's classification of igneous rocks, a scheme which has already been set forth elsewhere, and may or may not commend itself to other petrologists.

THE JAPANESE JOURNAL OF GEOLOGY AND GEOGRAPHY. Vol. I, Nos. 1 and 2. Tokyo, 1922.

WE have received copies of the first two numbers of this new periodical, published by the National Research Council of Japan. Each number contains original papers on various branches of geology and mineralogy, and about twenty pages of abstracts of papers on cognate subjects appearing in other Japanese periodicals. This feature will be very useful to European geologists. In the first number the paper of most general interest is an account of the Mud Volcanoes (Gas Vents) of Minbu, Burma, by T. Niiya: this is illustrated by some really excellent photographs reproduced as

plates. Indeed, the quality of the illustrations throughout is very high. We welcome this new periodical, which is to appear quarterly, as another link with the active development of geological science now in progress in the Far East, which is thus, by publication in English, made accessible also in Europe and America.

A Comparison of British and American Foundry Practice, with Special Reference to the use of Refractory Sands. By P. G. H. Boswell. pp. viii + 106, with 4 plates and 9 text-figures. Liverpool, University Press; London, Hodder and Stoughton. 4*s*. 6*d*. net.

THIS book deals chiefly with the technicalities of foundry practice in Britain and America, but it contains also an account of the composition and characters of those types of sands suited for use as moulds for iron and steel castings. In chapter V, certain American sands of this type are described in detail, but not very much information is given as to their geology. The book forms a useful supplement to Professor Boswell's well-known publications on British resources of sands suited for glass-making and other economic purposes, the special requirements of a moulding sand as regards composition and physical properties being well and clearly explained and illustrated by the results of chemical and mechanical analyses.

The Geological Story of the Isle of Wight. By the Rev. J. Cecil Hughes, B.A. pp. 115, with illustrations. London: Edward Stanford, Ltd. Price 5*s*. net.

THE author of this work has adopted the idea of writing a popular introduction to geology based almost exclusively on the study of the Isle of Wight. The plan has the obvious disadvantage that in the area in question there are no rocks earlier than the Wealden, but Mr. Hughes attempts to get over this deficiency by giving a hurried account of the other formations in a chapter towards the end of the book. Since the work is intended for the beginner, it is to be feared that the author may convey a wrong idea of the relative importance of the other and newer rocks in the formation of the land. The book, however, is not without merit, and in visitors to the Island may well arouse an interest in geological study by directing attention to local phenomena which otherwise would have been missed. The account is largely based on the Survey Memoirs of Mr. Osborne White, and is illustrated by figures of characteristic fossils drawn by Miss Maud Neal, as well as by diagrammatic sections and three excellent photographs of Gore Cliff and the Chalk at the Culvers and at Scratchell's Bay. The best chapter in the book is the one on the Island river system, which contains an instructive map of the old Solent river. In the previous

chapter it seems very unnecessary for the author to have devoted so much space to a discussion of a discarded astronomical theory of recurrent glaciation.

F. H. A. M.

The Geology of the London District. By H. B. Woodward. Second Edition, revised by C. E. N. Bromehead, with notes on the Palæontology by C. P. Chatwin. Mem. Geol. Survey England and Wales, 1922. 1*s.* 6*d.*

This volume is in reality a stopgap issued for use until the appearance of the memoirs on the 1 in. New Series maps, of which Sheets 269–70 have already been published. It is, to a certain extent, an unsatisfactory volume, in that its revisers have seen fit to reduce its size from 142 to 90 pages, making the descriptions of details and locations of sections, etc., appear more scrappy than they used to be, an effect which is heightened by the increased space devoted to detailed palæontological description.

The method of treatment remains the same, and though, of course, some stratigraphy has been revised (for example, the Red Rocks of Doubtful Age are put into the Devonian), a great deal of the matter is unaltered.

The publication of separate memoirs has curtailed the description of the Water Supply, and the pages on Town Geology have been omitted.

Somehow, the revised edition has lost some of the charm and fascination of the original, which must be regarded as unfortunate, as a volume of this size could hardly cover the details of the district; and in its old form the memoir was an attractive and interesting résumé of the geology, which can hardly be said of the present volume.

J. E. A. W.

On the Marundites and Allied Corundum-bearing Rocks in the Leydsdorp District of the Eastern Transvaal. By A. L. Hall, M.A. Trans. Geol. Soc. South Africa, xxv, 1922, p. 43.

The new type *marundite* has been established by the author for the margarite-corundum rocks of this district. They are holocrystalline, medium to coarse-grained rocks, characterized chemically by a high percentage of alumina (up to 70 per cent). The appearance of an allied type, the ruby-disthene marundite, is sufficiently uncommon to merit an abridged description. It consists of corundum (either as dense aggregates of pin-head size rubies or pale bluish crystals up to 1 inch in diameter), vivid emerald green mica, kyanite in long pale electric blue blades pearly-white margarite, and black tourmaline.

The marundites occur at the periphery of an acid plagioclase-pegmatite intruded into a varied basic series of serpentines, pyroxenites, hornblendites, etc. Between the marundite and the pegmatite is a zone of acid plagioclase rock, and at the junction of marundite and country rock is a development of talc. In the case where the country rock is hornblendite, the ruby-kyanite-marundite is developed instead of the normal type.

The author considers these types have been generated by a passage of silica into the country rock, which silica has interacted to form the talcose zone. The fact that the hornblendite contains enough silica to form talc is the reason the author gives for the appearance of the abnormal marundite. His contentions are upheld by the field-relations and chemical analyses, of which no less than nine were made of specimens dealt with in this paper.

J. E. A. W.

A Text-book of European Archæology, Vol. I: The Palæolithic Period. By Professor R. A. S. Macalister, Litt.D., F.S.A. pp. xiv+610, with 184 illustrations. Camb. Univ. Press, 1921.

SOME geologists are also archæologists, though probably few of the latter are acquainted with the science that deals with the ancient history of the earth. And yet the strata of the geologist may be truly said to pass up gradually, and without any "unconformity", into those that constitute the territory of Archæology. There appears to be no break, much less an "overthrust". Hence it may not be out of place for a geologist to offer a few remarks by way of criticism of this very learned and well-written book by an erudite professor. The printing, the paper and binding, etc., are well-nigh perfect, as might be expected of the Cambridge University Press. But after reading this work carefully, and more than once, the present writer feels impelled, being a geologist, to offer a little criticism on one or two matters. In the first place one may perhaps be allowed to suggest that the geological prolegomena are somewhat lengthy. Such questions as the origin of the earth and solar system seem a little out of place in such a work. In reviewing the past history of the earth the author is hardly correct in saying that no traces of life appear in pre-Cambrian rocks. He also omits the pre-Cambrian Ice Age. Secondly, on page 27, he appears to entertain a view of the erosive powers of a glacier which may perhaps be said to be out of date. Most of us are agreed that such a power must be very limited. Thirdly, the author's views on the vexed question of the Eoliths are, to say the least, somewhat strong! In short, he will not have them at any price, in spite of Ray Lankester and Benjamin Harrison and many others. Eolithists, as he calls them, are treated with scorn. Pliocene man he also rejects; but perhaps that question is more open to doubt. However, the learned author has given us a most valuable and comprehensive work which will

be welcomed by all students of the older Stone Age. The numerous references are very welcome.

H. N. H.

Catalogue of the Fossil Bryozoa (Polyzoa) in the Department of Geology, British Museum (Natural History). The Cretaceous Bryozoa (Polyzoa). Vol IV. The Cribrimorphs, Part II. By W. D. Lang. 8vo, pp. 404, 8 plates, 125 text-figures. London: Printed by order of the Trustees, 1922.

THIS volume is a continuation of Vol. III of the Catalogue published in 1921 and completes the Cretaceous Cribrimorph Cheilostomata. It deals with the Pelmatoporidæ—a group on which Dr. Lang has already published an illuminating essay on evolution (*Phil. Trans.*, 1917). Those who have followed the work of Dr. Lang and other recent writers will realize the value of the Polyzoa in zonal stratigraphy, especially in the Chalk and Tertiary formations. The general principles on which the work is based are given in an introductory essay in vol. iii, which should be read by all palæontologists and stratigraphists. The tables showing the zonal distribution of the species and the author's views on their phylogenetic relationship will be of great service to other workers.

Everyday Life in the New Stone, Bronze, and Early Iron Ages. By M. and C. H. B. Quennell. 8vo, pp. i–x, 1–119, 90 figures. London: B. T. Batsford, Ltd., 1922. Price 5*s.* net.

"THIS book . . . is primarily intended for boys and girls of public school age, but may be of interest to their elders." The authors write with evident enthusiasm and with first-hand knowledge of their subject, and their work should appeal to elders as well as to young people. Some of the illustrations may perhaps give the impression that, in some matters, our knowledge is more certain than is warranted by the facts known. For the benefit of younger readers it would have been well to have stated that some of the drawings (e.g. Glastonbury Lake village) are restorations and not actual views.

The Rift Valleys and Geology of East Africa. By J. W. Gregory. 8vo, 479 pp., with 20 plates and 44 text-figures. London: Seeley, Service & Co., Ltd., 1921. Price 32*s.* net.

THIS volume, like all Professor Gregory's work, is characterized by clearness of statement and by the fullness of its references to the previous literature of the subject, and it is accordingly invaluable as a summary of the present state of our knowledge of the area with which it deals.

In producing the book in its existing form the author has evidently had more than one object in view, and more than one class of reader. His chief interest lies in the rift valleys and the volcanic and other phenomena associated with them, and he writes on these matters as if he were addressing geologists. At the same time, he has wished to make the book generally useful as a handbook of the geology of Kenya Colony, and at times he has thought of possible readers whose knowledge of geology may be limited. The effect of this divided aim is perhaps most conspicuously shown in the chapter on fossil corals. He describes the characteristic features of a Rugose coral, and gives the meaning of the terms septum and dissepiment, while the greater part of the chapter is occupied by technical descriptions of new species, in which such words as columella, caespitose, epitheca, are freely introduced without explanation. These attempts to meet the needs of non-geological readers are too sporadic to be of much use to anyone, and might well be relegated to the glossary at the end; but they do not take up very much space. It may be said at once that the greater part of the book will not be very intelligible to anyone who has not a fair knowledge of geology. But there are chapters on prehistoric man, the East African caves, water-supply, mineral resources, and soils, which, though limited in scope, will probably be useful to non-geological readers.

About two-thirds of the volume is devoted to an account of the geology of Kenya Colony—the British East Africa of pre-war days—with special stress laid upon the rift-valleys. Another hundred pages deal with the relations of the geology of other parts to the Great Rift Valley, the view being extended from Lake Nyasa to Palestine and even including Madagascar. In the final chapter, which may be looked upon as the climax, towards which the book as a whole is intended to lead, the author expounds his view, which he has already developed elsewhere, as to the origin of the Rift Valley. He believes it to be a trough-like subsidence along the crest of a broad anticline, like the sinking of the keystone of an arch which sometimes (though not always) takes place when the abutments give way. And he imagines that the "foundering" which produced the Indian Ocean was equivalent in effect to the giving way of the abutments.

Whatever may be thought of Professor Gregory's conclusions, his book is certainly by far the most complete account in existence of the African rift valleys and the phenomena associated with them. It is illustrated by many photographic plates and by maps and sections in the text. Most of the plates are well reproduced, but some of the figures in the text are rather roughly drawn and not so clear as could be wished.

P. L.

A Summer in Greenland. By A. C. Seward. pp. xi + 100, with 29 plates and 2 maps. Cambridge University Press, 1922. Price 7*s.* net.

In this charmingly written little book, adorned by apt quotation, Professor Seward, now President of the Geological Society, gives a popular account of his trip to Greenland in the summer of 1921, when he spent a considerable time in exploring parts of the west coast and the neighbouring islands, especially Upernivik and Disko, together with the Nugssuaq Peninsula and the Umanak Fjord. The chief object of the expedition was the collection of fossil plants, but much attention was also paid to the living flora and to the general geology. Since the old whaling days Greenland has been little visited by Englishmen, and, indeed, entrance to the country is now strictly regulated by the Danish Government, special permission to land being essential. Consequently the information here conveyed at first hand as to some features of the geology of that little-known land is specially welcome, and we can but hope that Professor Seward may see his way to publish his geological observations in a more extended and formal style. The admirable illustrations, many of great interest to students of glaciology, are mainly from the author's own photographs.

The Ayrshire Bauxitic Clay. By G. V. Wilson, B.Sc. Mem. Geol. Survey, Scotland. pp. vi + 28, with 2 plates and 2 text-figures. 1922. Price 1*s.* 6*d.* net.

This remarkable bed of clay, which possesses very refractory properties, forms the uppermost part of the Millstone Grit series in the northern part of the Ayrshire coalfield. It has been formed by the "lateritic" decomposition of a contemporaneous series of basaltic lavas and ashes. The occurrences of this valuable material are described in detail and its origin is discussed, being attributed to subaerial weathering during a period of terrestrial conditions before the deposition of coal-measures began. Some of it appears to have been laid down in shallow lagoons, and some actually on a land surface.

The general meaning of the term "bauxitic" is discussed and illustrated by a useful diagram, showing in graphic form the relative composition of siliceous and bauxitic clays based on the amounts of alumina and silica present, as compared with the composition of pure kaolinite. Those clays showing an excess of alumina over the proportion needed to form kaolinite are classified as bauxitic, and those with silica in excess of the same ratio as siliceous. This is a simple classification, and should be widely applicable to clays of all kinds.

R. H. R.

SEASIDE AND COUNTRYSIDE IN EAST ANGLIA. Edited by PERCY LINDLEY. pp. 63. To be obtained from the Publicity Department, Liverpool Street Station, E.C.

THIS publication is in point of fact an advertisement issued by the Great Eastern Railway Company, and therefore belongs to a category not usually noticed in our columns. But it deals in an attractive style with a district much frequented by geologists, and in particular it contains several really good coloured plates of famous geological localities, such as the cliffs of Cromer, Sheringham, and Hunstanton. The last named is especially effective, bringing out the structure very clearly, and many geologists might care to possess a copy.

ON THE CORRELATION BETWEEN THE FLUVIAL DEPOSITS OF THE LOWER RHINE AND THE LOWER MEUSE IN THE NETHERLANDS AND THE GLACIAL PHENOMENA IN THE ALPS AND SCANDINAVIA. By Professor J. VAN BAREN. pp. 1–30, 20 plates, 3 sketches, and maps. H. Veenman, Wageningen, 1922.

THE text is largely critical, and the author concludes that the time has not yet come when the Scandinavian ice-deposits in the Netherlands can be parallelized with the terraces in Middle Europe, and with the phenomena of the ice-period in the Alps and Scandinavia.

The remarkable deposits of the neighbourhood of Ede, in Southern Holland, are described and illustrated by admirable photographs, and the new facts are of much importance to students of Pleistocene geology.

REPORTS AND PROCEEDINGS.

EDINBURGH GEOLOGICAL SOCIETY.

17*th January*, 1923.—Mr. T. Cuthbert Day, F.G.S., F.R.S.E., President, in the chair.

"The Leithies, North Berwick." By T. Cuthbert Day, F.R.S.E.

The Leithies consist of several masses of basalt appearing above the volcanic ash of the shore nearly 2 miles east of North Berwick station. Certain points of considerable interest are: the nature of the basaltic rock and its relationship to the volcanic ash; and the peculiarity of many dykes, and other forms of sedimentary material enclosed in the basalt. The apparently separate outcrops of basalt were all shown to be identical in composition, that is, a monchiquite basalt of typical form. A close study in the field of each outcrop of basalt revealed their intrusive nature, and also that there were the remains in each case of a former indurated cover of ashy and other sediments. Evidence was also brought forward to show that the Leithies, looked at collectively, might be considered as constituting a broken down irregular laccolith in the volcanic ash of

the shore, and having three distinct feeders. A feature of special interest at the Leithies is the peculiar nature and appearance of the sedimentary material enclosed in the basaltic rock. Much of this material is evidently derived from the volcanic ash of the shore, and can be easily recognized in its indurated form ; but a large part, too, consists of very fine sedimentary matter, much indurated, and not like the ash in appearance. Its chemical composition was, however, much the same, both containing a considerable amount of carbonates of lime and magnesia. A survey of the district showed that there were many beds of this fine material deposited in the ash at various horizons, and also in close proximity to the Leithies. These beds seem to be composed of the fine material produced by denudation of the volcanic ash, and deposited from time to time during its accumulation. The fine sedimentary material enclosed in the basalt, besides being indurated, was apparently intensely corroded by the basalt, and the latter wherever in contact with the sedimentary material was vesicular to an extraordinary degree, and, moreover, in such places the basalt took on a vitreous appearance much in contrast with its general nature. It was suggested that this marked vesicular nature of the basalt was due to the chemical action of the molten magma, resulting in the evolution of carbon dioxide from the carbonates present, and that a considerable assimilation of the sedimentary material by the molten basalt had taken place. This suggestion was put to the test of experiment, and it was found that when a fragment of the same sediment was introduced into a crucible containing molten basalt, it was immediately attacked by the latter with evolution of carbon dioxide ; and when the experiment was stopped before the fragment of sediment had quite disappeared, and the cold melt was broken up, specimens were obtained identical in appearance with those obtained from the Leithies. Other experiments showed that the molten basalt could easily incorporate 25 per cent of its weight of fragments of the fine sediment in thirty minutes, forming a perfectly homogeneous black glass. A study was made of the dykes of fine sedimentary material in the intrusive basalt, of which there are very many, varying greatly in thickness and position. Most of them consist of material identical with that already noticed, and some have much ash in their composition. They are much indurated and the sides of all the larger dykes are penetrated by the basalt in a very vesicular state. There is no evidence of horizontal stratification in any of them. They are jointed vertically and horizontally in many places, and in all of them there is a tendency to jointing or splitting in a longitudinal direction following the course of the dykes. Many of them are curiously distorted, squeezed, and drawn out owing to differential movements in the invading magma. A comparison was drawn between these dykes and some of a similar nature occurring in the intrusive dolerite of the Hummel Rocks at Gullane.

24th January, 1923.

"The Bushveld Igneous Complex of the Transvaal." By S. J. Shand, D.Sc., Ph.D.

The geology of the great mass of igneous rocks, known as the Bushveld Complex, which occupies an immense area in Central Transvaal, was described. The importance of this complex for economic geology is already recognized, for it is the source of all the tin ore in the Transvaal, and of other ores as well, but it has an even greater interest as an unsurpassed object lesson in the process of igneous geology and as a touchstone for petrologic theories. The complex occupies a great basin formed by sedimentary rocks of the Transvaal System, which dip inwards from all sides towards the centre of the basin. The highest rocks composing the basin are quartzites and slates, but beneath these there is a thick limestone formation. The igneous magma, coming up from below, cut its way through the limestone and the Pretoria beds, and spread out in the form of a huge lenticular cake between these beds and a roof of younger rocks which have now been largely denuded away. The cake was not all formed at once, but layer by layer. The lowest layer is composed of norite and ultra-basic rocks, and is half a mile to a mile thick. Above it come one or more thinner layers of felsitic lavas. After all these rocks had become completely solid they were cut by fissures and pipes through which later igneous matter was forced up, giving rise to trachytic and phonolitic lavas at the surface and to syenites and nepheline-syenites underground. Thus the complex includes both concordant and transgressive intrusions, both lavas and deep-seated rocks, and every variety of igneous rock from highly magnesian (olivine rocks) to highly calcic (anorthosites), highly siliceous (granites), and highly alkaline (nepheline-syenites). As regards bulk, however, norite and granite are in overwhelming predominance, and all the other rocks seem to have been developed from these by various special reactions, among which reaction with limestone has certainly played a part.

Yorkshire Geological Society.

At the annual meeting of this Society, held at York on 2nd December, 1922, the President, Mr. G. W. Lamplugh, F.R.S., delivered an address entitled "A Review of the Speeton Clays", in which he summarized the new knowledge gained during the last thirty years from fresh investigations of the section and from the correlative work of foreign geologists and palæontologists. The stratigraphical particulars previously arrived at for the lower two-thirds of the clays had been confirmed, and some progress had been made toward filling in the details of the remaining portion, which was, however, still imperfectly known. In commenting on the tumbled state of the exposure, the speaker mentioned that conditions had been even worse of late years than formerly, but seemed likely soon to improve.

The assiduous spade-work of Mr. C. G. Danford, and the continued watchfulness of Mr. J. W. Stather and other Hull geologists, had meanwhile added considerably to our knowledge of the fauna by extending the known range of some of the characteristic forms and by discovering others serviceable for correlation purposes. The use of Belemnites as a basis for classification had been justified, and had been still more closely applied in north Germany by Dr. E. Stolley, who claimed that narrower zones than had been hitherto recognized were distinguishable by means of the separable members of mutation-series in the different Belemnite-stocks; the names customarily in use for the Speeton forms being all regarded by him as "collective" or "group" names, embracing many species. Difficulties in testing this closer subdivision at Speeton arose from the condensed character of the deposits, as well as from the scarcity of adequate exposures. Some discrepancies in the correlative range of the fossils seemed, however, to imply that the appearance and disappearance of some of the life-forms were affected by local circumstances and were not strictly synchronous with the foreign occurrences.

The Ammonites occurring in the upper part of the "Bel. lateralis beds", supposed by Leckenby and Judd to be Portlandian species, were now known to have been wrongly identified, and really belonged to a group (*Polyptychites*) characterizing a portion of the lowest stage (Valanginien) of the Lower Cretaceous on the continent. Therefore, the greater part, if not the whole, of the "Bel. lateralis beds" must be regarded as belonging to this stage of the Lower Cretaceous. The "Bel. jaculum beds" were roughly equivalent to the Hauterivien of the continent, and the major portion of the "Bel. brunsvicensis beds" (still imperfectly known) to the Barrêmien.

Of particular importance was the discovery of Belemnites of the *Ewaldi* group in the top beds of the Speeton Clays in marls previously classed along with the "Bel. minimus marls". These beds were only to be seen in slipped masses, partly obscured by chalk-talus; but they had been observed in this position at various times by Mr. Danford and Mr. Stather, as well as by the speaker, and Mr. Danford had found that these "Ewaldi" belemnites occurred only below a band of phosphatic nodules previously recorded. The Belemnite thus occupied the same position as in Germany, where, however, the deposits were much thicker and had been subdivided into several zones. The same Belemnite had been found also by the speaker in the Hythe Beds of Kent. There was reason to believe that the nodule-band between the "Bel. Ewaldi bed" and the "Bel, minimus marls" belonged to the Lower Gault, along with some portion of the overlying marls. It was uncertain whether the whole of the beds present in the hidden section had been revealed in the slips. Further discoveries might still be made.

Liverpool Geological Society.

December 12th, 1922.—Professor P. G. H. Boswell, O.B.E., D.Sc., F.G.S., President, in the chair.

The following papers were read :—

1. "A note on the Glacial Geology of the Alwen Valley above Pont-yr-Alwen." By H. J. F. Gourley, M.Eng., M.Inst.C.E., F.G.S.

The Alwen Valley is an ancient pre-glacial valley, deeply eroded, in the Denbigh Grit Rocks (Wenlock), and now filled with glacial deposits, mostly of boulder clay, similar to that of the Dee. The head-waters of the Alwen are now impounded, to a level of 1,190 feet, for the use of Birkenhead by a dam constructed three-quarters of a mile above Pont-yr-Alwen. The form of the rock surface, as far as could be inferred from exposures in the excavation for the foundations of the dam and in trial holes, was briefly described. The old channel of the pre-glacial stream was considered to lie about three-eighths of a mile south of the present Alwen, and to pass through Llyn Dau-y-Chain. Its depth below the present river-bed would be considerable.

2. "The Structure and Succession of the Silurian Rocks in the Eastern Part of the Denbighshire Moors." By Professor P. G. H. Boswell, O.B.E., D.Sc., F.G.S.

A brief account of the work of Ramsay, Marr, McKenny Hughes, and Elles was given, followed by a detailed description of the succession of the Ludlow deposits of the eastern part of the Denbighshire Moors. The rocks consist mainly of mudstones, siltstones, and fine sandstones, often flaggy in character, and usually graptolite-bearing. Most of the graptolite-zones of the Ludlow as worked out on the Welsh borders are present, succeeded by the *Dayia navicula* mudstones. Lithologically, the sequence most nearly resembles that recently described by L. J. Wills in the Llangollen district. The zone of *M. tumescens* is, however, well-developed in the Denbighshire Moors, where it lies above beds of Nant-y-Bache type. Rolling siltstones and mudstones, with abundant graptolites (the Nant Glyn Flags, of *nilssoni* zone, as described by Dr. Elles), occupy a large part of the area. The diminution in intensity of cleavage as the series is ascended, and the simple block-faulting, were also described.

January 16th, 1923.—Professor P. G. H. Boswell, O.B.E., D.Sc., F.G.S., President, in the chair.

The following papers were read :—

1. "The Petrology of the Permian Rocks of the Parbold District." By Miss Mabel Workman, B.Sc.

The outcrops of Lower Permian rocks described occur in South-West Lancashire: at Bispham, six miles north-east of Ormskirk, in a little dell known as Skillaw Clough, and in Bentley Brook near by. The Millstone Grit of the same neighbourhood was also described, for comparison. The heavy minerals obtained from the

Permian Sandstones included garnet, zircon, rutile, tourmaline, monazite, and hypersthene, all of which were also found in the Millstone Grit. From the assemblage of minerals it was considered that the sandstones were derived partially from the Millstone Grit, and were apparently deposited under arid but not desert conditions.

2. "On some Lamprophyre Dykes of the North of England (with special reference to the Cronkley Dykes)." By David Williams, B.Eng., B.Sc.

The results of the author's study of the dykes and sills genetically associated with the Shap Fell intrusion may be summarized as follows:—

(1) After the intrusion of the Shap granite in Devonian times, and after the intrusion of a mixed series of dykes, there was left a magma, which by gravitative differentiation separated into an upper acid and a lower basic division.

(2) Acid crystals which crystallized out at an early date in the upper layer were enabled, by virtue of their density, to sink into the more basic lamprophyric magma below, thereby producing cognate xenocrysts in the latter.

(3) There is the peculiar occurrence in all the Cronkley dykes of a mineral which is regarded as pseudomorphous after melanite garnet.

(4) The dykes have effected singularly little alteration in the surrounding shales beyond a slight induration near contact, and the production chiefly of new biotite, chlorite, and quartz.

(5) The Cronkley intrusions are of Devonian age, and represent some of the latest, if not the very latest, of the minor intrusions which followed, and were so closely related to, the Shap Fell Granite.

Mineralogical Society.

9th January.—Dr. A. E. H. Tutton, Past-President, in the chair.

A. Brammall and H. F. Harwood: Dartmoor occurrences of (1) rutile, brookite, and anatase; (2) zircon. (1) Anatase, with less abundant brookite and scanty rutile, is common in Dartmoor stream-sands, etc. Anatase and brookite, absent from the unaltered grey granite, have been found in pneumatolysed rocks, especially "red" granites, and the mode of genesis of these two minerals is discussed. Data provided by chemical work on "baueritized" Dartmoor biotite (containing about 1·8% TiO_2) and by the occurrence of anatase granules encrusting detrital grains of ilmenite are examined in their bearing on the possibility that some anatase may have developed (or existing crystals may have continued to grow) in detrital material after sedimentation. (2) Two strongly contrastsd kinds of zircon crystals are described: differences in crystal habit, nature of inclusions, and mode of occurrence in the granite suggest that the dominant kind, which is tawny, zoned, and rich in inclusions, crystallized out from the magma early, and that the subordinate